# GEOSPATIAL DATABASE AND PRELIMINARY FLOOD HYDROLOGY MODEL FOR THE LOWER COLORADO BASIN

**by**

**Sarah Anne Stone, B.S.**

**Thesis**

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

**Master of Science in Engineering**

**The University of Texas at Austin**

**May 2001**

# GEOSPATIAL DATABASE AND PRELIMINARY FLOOD HYDROLOGY MODEL FOR THE LOWER COLORADO BASIN

**Approved by**
**Supervising Committee:**

---

**David Maidment**

---

**Francisco Olivera**

---

**Randall Charbeneau**

# ACKNOWLEDGEMENTS

I would like to thank Dr. David Maidment and Dr. Francisco Olivera for their help, energy and guidance during this research. Dr. Maidment's enthusiasm about this work's importance and potential and Dr. Olivera's wise recommendations based on a thorough understanding of my project made a wonderful combination that greatly enhanced the quality of my education.

In addition, I will always be grateful to the Lower Colorado River Authority for funding this research. I also offer a special thanks to Dr. Martina Bluem and John McLeod at the LCRA for their time, ideas, and direction.

I was lucky to meet such a great bunch of friends at UT and I'd like to thank them, especially the CRWR crew, for making the past two years tons of fun. It's been great to be surrounded every day by people who make me smile.

Finally, I'd like to thank my parents and the rest of my family and friends back in Connecticut for all their interest in me, prayers, phone calls, frequent visits, and constant love.

May 4, 2001

# ABSTRACT

## Geospatial Database and Preliminary Flood Hydrology Model for the Lower Colorado Basin

Sarah Anne Stone, M.S.E.

The University of Texas at Austin, 2001

Supervisors: David Maidment and Francisco Olivera

A detailed methodology is presented for using a variety of standard and specialized data sources to construct a comprehensive geodatabase for the Lower Colorado River basin in Texas and create a preliminary flood hydrology model from the geodatabase. A stream network is prepared in a GIS environment from the National Hydrography Dataset, creeks data produced by the Capital Area Planning Council and the City of Austin, and digitizations based on the USGS Digital Orthophoto Quarter-Quadrangles and USGS Digital Raster Graphics Quadrangles. A measure system is implemented along the reaches. The National Elevation Dataset is used together with the streams to delineate watersheds with the procedure used by CRWR-PrePro. Watershed outlets come from stream confluences, intersections of USGS hydrologic cataloging units with streams, bridges in the Texas Department of Transportation county roads coverages, LCRA gage locations, and points selected specifically for the shapes and sizes of

watersheds they produce.  Parameters for hydrologic modeling are determined for each of the watersheds from the National Land Cover Dataset, a Lower Colorado River Authority land cover dataset, STATSGO soils data, and the streams and watershed topology.  The parameters are transferred to an HEC-HMS basin file for which calibration and use for hydrologic modeling in conjunction with hydraulic modeling for flood analysis is planned.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER 1: INTRODUCTION

## 1.1 BACKGROUND AND MOTIVATION

The Colorado River is an important resource in central Texas, a resource that must be well managed. One facet of river management is the prevention of damage from flooding. A hydrologic model of the basin can be used to predict the timing, area, and extent of flooding and consequently be a key tool in flood damage management. This thesis describes the process of creating a preliminary flood hydrology model of the Colorado River basin as a part of the Lower Colorado River Authority's efforts to reduce flood damage.

The Lower Colorado River Authority (LCRA) in Austin, Texas is the agency responsible for managing the use and conservation of the Colorado River's resources. Created by the Texas legislature in 1934, it is a conservation and reclamation district funded entirely by revenues from water and electric sales. The LCRA's coal, gas, hydroelectric, and wind power plants supply power to over a million people in Texas. Six dams on the Colorado River, operated by the LCRA, protect the region from flood damage and provide water supply for agriculture and municipalities. The LCRA also operates parks, monitors water quality, and supports a variety of community development projects (LCRA, 2001).

Currently, the LCRA is undertaking a large project to improve the organization's ability to predict flooding and understand the effects of flooding in the basin. The project includes hydrologic modeling of the basin, hydraulic modeling of the main channel and some of the larger tributaries, development of a method for digital flood insurance rate map (DFIRM) preparation, and creation of advance flood inundation maps to assist public officials with evacuation decisions. According to John McLeod (personal communication, April 26, 2001), the LCRA has spent about $3.8 million on aerial photos of the area within which lies the 500-year floodplain of the main stem of the Colorado River between the Burnet-Lampassas County line and the Gulf. Over 300 cross-sections of the Colorado River and three important tributaries (Llano, Pedernales, and Sandy Creek) have been surveyed, and bathymetric surveys have been done for the reservoirs on the main stem operated by the LCRA. The information obtained will improve the precision of floodplain mapping. The LCRA will be the map custodian for the resulting floodplain maps, as a Cooperating Technical Community Partner for the Federal Emergency Management Agency (FEMA) (Maidment and Olivera, 1999).

The LCRA provided funding for the Center for Research in Water Resources (CRWR) at the University of Texas at Austin to employ two graduate students to prepare a preliminary hydrologic model of the basin and do a pilot study of DFIRM creation in the Highland Lakes region. Kevin Donnelly at CRWR did the DFIRM preparation.

The preliminary hydrologic model described in this thesis is a set of files that can be used as input to HEC-HMS, the hydrologic modeling program created by the U.S. Army Corps of Engineers. The files contain watershed and stream connectivity and runoff parameters such as slopes and infiltration rates, and are accompanied by a set of Geographic Information Systems (GIS) files that serve as a basis for the watershed parameters calculated. Because of the level of detail to which the GIS data is compiled and attributes are calculated, the new hydrologic model will be superior to the LCRA's existing methods of flood prediction and floodplain delineation.

Halff Associates, Inc., a consulting firm with headquarters in Dallas, Texas, has contracted to use gage data to calibrate the preliminary HEC-HMS model, preparing it for use. Halff Associates, Inc. will also do reservoir modeling and channel modeling based on existing cross sectional data as well as cross sections extracted from the LCRA's new aerial photography. The combined modeling results will be used to prepare new floodplain inundation maps. The 10-year, 50-year, 100-year, and 500-year floodplains will be used to update the DFIRMs.

## 1.2 OBJECTIVES

There were four primary objectives of the research.

1. Prepare a single-line network of the streams in the Colorado River Basin.
2. Delineate watersheds within the study area.
3. Compute hydrologic parameters for the watersheds.
4. Create a preliminary HEC-HMS model of the basin.

Preparation of the initial network involved merging sections of stream from the National Hydrography Dataset, fixing gaps and loops, and using multiple additional data sources to edit reach locations in areas where further accuracy was needed. After the network was created, every vertex in the network was given a coordinate specifying the vertex's distance along the network from the coast. The reaches from the LCRA that make up the Colorado centerline were attributed with NHD reach codes to allow the centerline's use as a stationing line for linear referencing.

Watersheds were delineated from digital elevation data and two different sets of outlet points. The elevation data was processed using a well-established procedure that prepares the grids for use in watershed delineation. The outlet points were selected from confluences, gages, bridges, and other points chosen based on watershed shapes and sizes the outlets would produce.

The hydrologic parameters computed for the watersheds were in support of the modeling planned by the LCRA. Watershed area, initial loss, uniform loss, flow path length, slope percent urbanization, and percent impervious cover were calculated from land cover, soils, watershed shapes and sizes, elevations and stream paths.

The network connectivity and many of the watershed parameters were incorporated into an HEC-HMS basin file, a text file used as input to HEC-HMS. The basin file is intended for use in hydrologic modeling within the study area.

## 1.3 STUDY AREA

The Colorado River basin extends across the middle of Texas. The LCRA study includes the areas within the LCRA's jurisdiction, the Lower Colorado River Basin, as outlined in Figure 1.1. Stacy Dam, the furthest upstream of the major dams on the Colorado, marks the most upstream point in the study area. The drainage area for the entire basin is 102,183 $km^2$, with the drainage area for the LCRA study area comprising 54,728 $km^2$ and the upstream drainage area comprising 47,455 $km^2$.

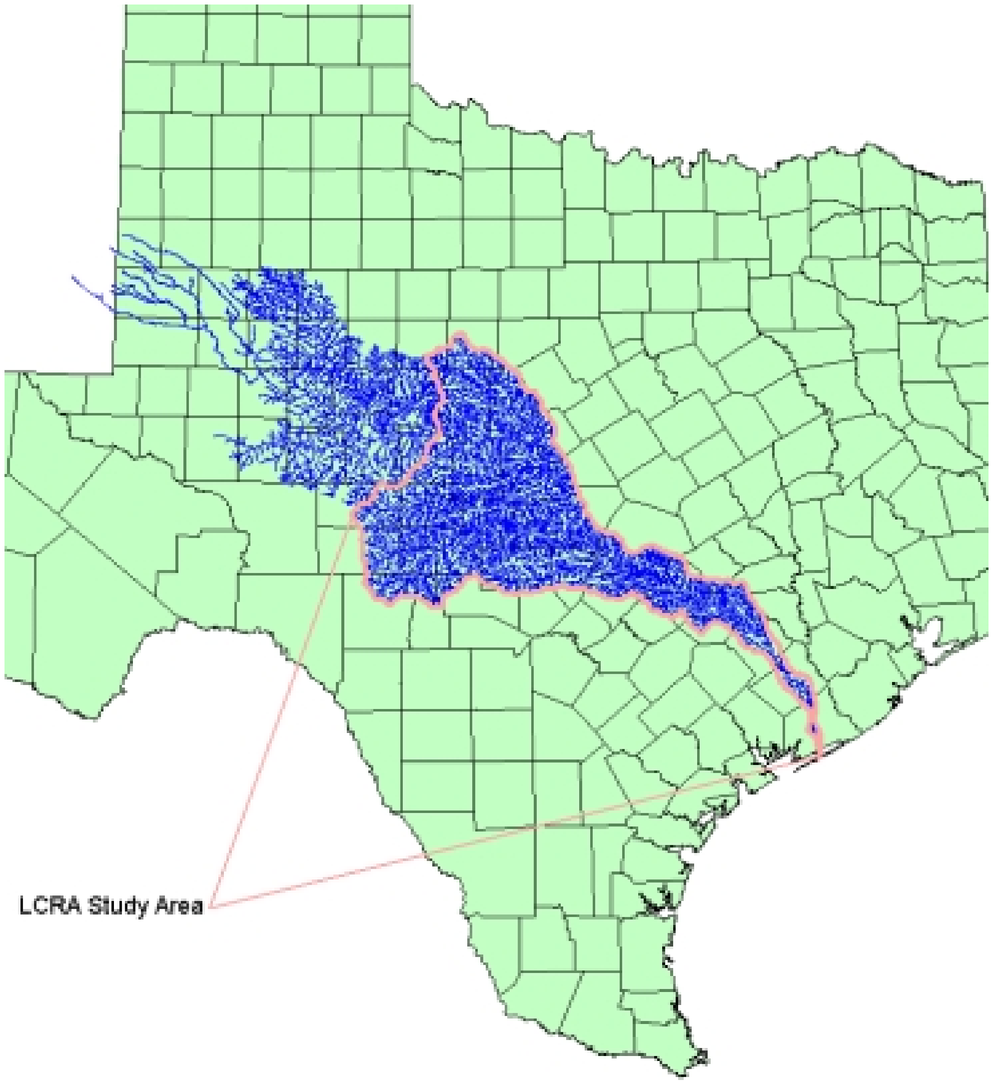



Figure 1.1. The Colorado River Basin

Austin, Texas is the largest city in the study area, just downstream of the Highland Lakes region. The Highland Lakes region is home to the major reservoirs operated by the LCRA, the largest of which are Lake Travis and Lake Buchanan.

## 1.4 OUTLINE

This thesis describes the process of creating a comprehensive geospatial database for a river basin and using this data and GIS tools to build a preliminary hydrologic model, in the form of an HEC-HMS basin file. Chapters 1 and 2 contain background information and a literature review. Chapter 3 discusses sources of data used in the project, the origin and accuracy of these data, and map projections and measurement units used for this project. Chapter 4 gives a conceptual overview of the methods employed for linear referencing, watershed delineation, parameter calculation, and HEC-HMS schematic creation, as well as discussing the software tools that were used. Chapter 5 gives a detailed description of the process employed. The data description, methods, and procedure chapters are presented in a way meant to teach a moderately experienced GIS user to apply a similar procedure to a new river basin and obtain a similar result. Results are discussed in Chapter 6, and summary and conclusions are provided in Chapter 7.

Four CDs and seven appendices are included with the document. Appendix A contains curve number and constant loss rate tables. The reference frame parameters used for ArcGIS 8.1 feature datasets containing Colorado basin data are located in Appendix B. Appendix C contains the calculation text used to define a measurement system on the streams. Appendix D contains the text of projection files used for the project. In Appendix E is a listing and description of each of the files on each of the four CDs included with this thesis. The CDs contain the results of this research and many supporting files. A list of ArcInfo commands for the delineation of watersheds around lake boundaries is included in Appendix F. Appendix G contains a list of shapefiles to which the ArcGIS Hydro Data Model was applied.

# CHAPTER 2: LITERATURE REVIEW

Previous work pertaining to this project was reviewed. Literature about watershed delineation with CRWR-PrePro and similar methods, studies using HEC-GeoHMS, and projects involving linear referencing is discussed in this chapter.

Many studies have been done on the use of GIS for automated watershed delineation. These methods usually involve processing a digital elevation model (DEM) to produce a flow direction grid and a flow accumulation grid from which watersheds are delineated. GIS can then be used to compute hydrologic parameters for the watersheds. Once the watersheds and parameters are defined, tools exist for importing these elements into standard hydrologic models.

CRWR-PrePro has been used for automated watershed delineation, parameter calculation, or HEC-HMS basin file creation in many research and professional projects, including those by Ahrens and Maidment (1999), Hudgens and Maidment (1999), Anderson (2000), Andrysiak and Maidment (2000), Asante *et al.* (2000), Mason and Maidment (2000), and Osborne *et al.* (2000).

Hudgens and Maidment (1999) and Mason and Maidment (2000) used CRWR-PrePro with similar data sources to those presented in this thesis, and offer some relevant conclusions about DEM resolution, slope, the “stream buffering” process, and quality control.

The accuracy of watersheds delineated from 1:250,000 scale DEMs with an approximately 90-meter cell size was assessed compared to those from 1:24,000 scale DEMs with an approximately 30-meter cell size. Although processing times and file sizes are about 10 times larger with 1:24,000 scale DEMs, it is strongly recommended that they be used as opposed to the 1:250,000 scale DEMs when doing studies of a basin-wide scope (Mason and Maidment, 2000 and Hudgens and Maidment, 1999). Use of 1:250,000 scale DEMs results in delineation errors, primarily because of stream short-circuiting caused by the vector stream network burned into the DEM being of a larger scale than the DEM. Delineations from 1:250,000 scale DEMs used in conjunction with a 1:100,000 scale reach network do not produce satisfactory results without an extensive quality control process. Delineations with a 1:24,000 scale DEM and 1:100,000 scale streams produce much better results without the need for so much manual checking (Hudgens and Maidment, 1999). In some instances file sizes and processing times can become unmanageably large when using smaller scale DEMs, but in general DEMs with less than 20 million cells are small enough to reasonably work with (Mason and Maidment, 2000).

Terrain slope is an important factor in certain watershed delineations. It was determined by Ahrens and Maidment (1999) that low average terrain slope was a cause for errors in watershed size when the average watershed slope is less than 0.0008 m/m. A more comprehensive comparison by Mason and Maidment (2000) revealed that errors from low terrain relief become more likely when the average slope is less than 0.002 m/m. These errors are clear with delineations from 1:24,000 scale DEMs but not from smaller scale DEMs, probably because with smaller scale DEMs other errors conceal the errors caused by low slope.

The stream buffering process discussed by Mason and Maidment (2000) is a way to eliminate error in watershed delineation caused by an abrupt boundary at the edge of the basin. The standard practice without stream buffering is to only burn in streams that fall within a pre-defined basin boundary. Burning streams into the DEM not only from the network being delineated but also from surrounding basins a 10 kilometer buffer distance away from the target basin results in a more accurately delineated basin boundary.

A quality control process for increasing the probability of correct watershed areas was proposed by Hudgens and Maidment (1999). If the original vector stream network is of a larger scale than the DEM, the DEM-derived stream network should be compared to the original vector stream network to be sure there is no stream short-circuiting. If any watershed areas are available before the delineations, they should be compared to the delineated watershed areas and reasons for any discrepancies should be determined. Boundaries of small watersheds should be checked for correctness against digital raster topographical maps. A study by Mason and Maidment (2000) determined that watersheds delineated from 1:24,000 scale DEMs with areas of less than about 0.15 square miles should be thought of as “small” and thus be checked against digital raster graphics. Whelan (1999) found the use of a vector streams network, land use/land cover data, topographic maps, and hydrologic cataloging unit areas necessary to manually ensure delineation quality for all watersheds in a study of watershed delineations from 1:250,000 scale DEMs. Whelan's study involved use of the ArcView Spatial Analyst Hydrologic Modeling extension, and followed a similar methodology to that in this thesis but without the use of burned in streams.

An Albers map projection is generally used for watershed delineation since watershed area is such a critical parameter, and the Albers projection preserves area (Hudgens and Maidment, 1999).

The functionality and methodology of HEC-GeoHMS, developed as part of a Cooperative Research and Development Agreement between HEC and ESRI, was based directly on that of CRWR-PrePro. HEC-GeoHMS has the advantage of providing the user with a choice between a lumped modeling approach in which hydrologic parameters are averaged over each basin and the ModClark method, a distributive modeling approach in which hydrologic parameters are grid based with spatial variation within the basin (U.S. Army Corps of Engineers, 2000).

Since HEC-GeoHMS was only released in July of 2000, few case studies have been done on the use of HEC-GeoHMS for watershed delineation and parameter calculation. The U.S. Army Corps of Engineers Sacramento District and the Hydrologic Engineering Center (HEC) recently completed a study of the use of GIS, HEC-GeoHMS, and HEC-HMS for hydrologic modeling in the Sacramento and San Juaquin River Basins in California. The Digital Elevation Models (DEMs) were assembled by McPherson and Hennerman (2000) before the National Elevation Dataset (NED) became available. A brief comparison was made of the NED to the national datasets used for the California study. The conclusion was reached that the NED and the original un-improved DEMs have similar amounts of error carrying over from the source data, but much less GIS expertise is required to prepare NED data for use.

Dunn *et al*. (2000) continued the study by asking eleven 2-person modeling teams to prepare the necessary grids and delineate watersheds of 50 to 500 square miles each in each of eleven subbasins within the Califonia study area. The teams used HEC-GeoHMS to calculate hydrologic parameters based on watershed boundaries and elevation grids, and determined additional parameters based on field data. The resulting hydrologic models were run in HEC-HMS and calibrated with gage data. It took 10 months to complete the modeling of the 60,000 square mile study area.

A new process was used in this thesis for assignment of measures along streams. This is a way of giving a point on a stream an m coordinate containing a measure value, in addition to its x and y coordinates. River miles and highway miles are common units of measurement. Linear referencing has been used extensively in the transportation and utilities (gas and oil distribution) industries. Calculation of river miles with GIS has been less thoroughly studied in the water resources field than in these other fields.

Previous studies of the use of GIS for linear referencing in rivers used the dynamic segmentation capabilities of ArcInfo. The standard process involves building an ArcInfo coverage of a river network where the digitized direction matches the flow direction. Sections of the river network are built into systems called routes. Event tables are built on top of the routes. Each entry in the event table stores a starting and ending measure for a segment on the route plus an identifier for the reach on which the segment lies. This is how information about a line can be made available for every vertex rather than just for the line as a whole. A less elegant way of making this stored information available at every vertex is to break the line at every vertex, but breaking the line requires additional memory (Davis, 1999).

In some cases, the linear referencing information that can be made available at every vertex is not precise enough. A good solution would seem to be to add more vertices, but as Hargrove *et al.* (1995) explain, adding additional vertices to the line with the densify command in ArcInfo actually increases the total length of the line as it appears in the arc attribute table (*.aat), even though each of the new vertices falls exactly on the line. To avoid this problem, Hargrove *et al.* used ArcInfo's Thiessen polygon generator to generate polygons around each of the points on the river of known measurement. The polygons and the known measurements could be used to interpolate measures to other points on the river without the need for adding additional nodes.

Relative measures were initially considered for this thesis as a way to prevent misleading measure values due to differences in scale within the network. Relative measures are expressed as percentages of total reach length, while absolute measures are expressed in absolute units such as feet or kilometers. Tate *et al.* (1999) used relative measures so as to avoid such distortions. Tate's project involved transferring cross sectional data from an HEC-RAS model to a GIS representation. The position of each cross section was known along the HEC-

RAS centerline, but the GIS centerline came from a different data source than the HEC-RAS centerline, and consequently had a slightly different scale. To determine the position of a cross section on the GIS centerline, the cross section's position along the HEC-RAS centerline was calculated as a percentage of the distance between two fixed stationing points, such as bridges. In the GIS environment, the cross section was placed on the GIS centerline at the same calculated percentage of the distance between the two stationing points. In this way, there could be a difference in the absolute measure along the stream between the two modeling environments, but the location of the cross section on the map was approximately the same for each.

The literature review makes it clear that automated watershed delineation from the 1:24,000 scale National Elevation Dataset is far preferable to delineation from the previously used 1:250,000 scale elevation data, or even from the 1:24,000 scale data before it was compiled into the National Elevation Dataset. The judiciousness of checking automated watershed delineation results before relying on them was also emphasized in the literature, although quality of source data and required quality of delineation controls how much checking should be done. HEC-GeoHMS is similar to CRWR-PrePro in method of use and in the results that it produces.

The literature revealed that the usual process for assigning measures to vertices of reaches requires a thorough understanding of workstation ArcInfo commands and ArcInfo table manipultation or specialized tools such as those available for traffic engineering applications. When doing linear referencing, caution must be used when adding nodes to a reach or working with reaches of varying scales.

Although previous studies of geodatabase construction and the CRWR-PrePro method for hydrologic model creation have been done, this one is the most comprehensive completed on a basin scale for which extensive use in river management is planned.

# CHAPTER 3: DATA DESCRIPTION

## 3.1 DIGITAL DATA SOURCES

A wide variety of point, line, polygon, grid, and image data were used for the project. They are described in the following sections.

### 3.1.1 Stream Network

Multiple sources of stream data were used to create the backbone stream network used for watershed delineation, linear referencing, and model creation. The combining of stream data sources is described in Section 5.1.

#### *3.1.1.1 National Hydrography Dataset*

Most of the stream data used for the project comes from the National Hydrography Dataset (NHD). The NHD was created by the USGS and EPA and released in 1999. The scale is 1:100,000 in most areas. The reach locations in the NHD come primarily from the EPA Reach File Version 3 (RF3), which was derived from 1:100,000 scale USGS digital line graphs (DLGs) (USGS, 2000). According to Keven Roth at the USGS (personal communication, December 3, 1999), the 1:100,000 scale DLGs were created by piecing together 1:24,000 scale DLGs, which were digitized from USGS topographic maps.

The capture conditions for a reach in the RF3 and hence the NHD as well are most closely described by the capture condition for a stream in the 1:24,000 scale DLGs, according to Keven Roth (personal communication, December 3, 1999). The definition of a 1:24,000 scale DLG stream is a stream that either flows from a pond or lake; is in an arid region and carries water throughout the year except when there's an extreme drought; or is more than 2500 feet long (USGS, 1997).

The NHD contains a variety of features, but in this study only the route.rch files were used, since these provide a single line network without features such as coastlines and lake boundaries that would impede the processing to be done.

Each line segment in the NHD contains an important attribute called the reach code, contained in a field called RCH_CODE. There is a unique reach code for each reach in the United States. The first 8 digits of the code are the hydrologic unit code for the hydrologic cataloging unit that the reach is inside. The last 6 digits of the reach code are an arbitrary number assigned to that reach in the cataloging unit (USGS, 2000).

#### *3.1.1.2 CAPCO and ASI Networks*

There exists in the 10 counties surrounding Austin a set of files maintained by the Capital Area Planning Council (CAPCO) that contains a representation of each of the river locations at a 1:4800 map scale, the assured level of accuracy maintained in the feature creation process. The 1:4800 scale line work was digitized from enlarged 1:30,000 flight scale digital orthophotography compiled at 2-foot pixel resolution. The aerial photographs were taken by Analytical Surveys, Inc. (ASI). The CAPCO files cover Bastrop, Blanco, Burnet, Caldwell, Fayette, Hays, Lee, Llano, Travis and Williamson counties (CAPCO, 2001).

The CAPCO creeks network for Travis county was created from aerial photography taken at a 1:18,000 flight scale with a finer 1:9600 flight scale within the City of Austin. The map scale and hence level of assured accuracy of the digitizations from the enlarged photography is 1:2400 for the county and 1:1200 for the city (CAPCO, 2001). The creeks within the city were checked for correctness and further modified by the Watershed Protection Department of the City of Austin to connect small unintentional gaps and disconnected arcs resulting from segments not visible in the aerial photos. The department used 2-foot contour lines; data on concrete channel, pier, dock, and dam locations; USGS topographical maps; storm sewer maps; digital orthophotos; and field investigations in their corrections (Osborne *et al.*, 2000).

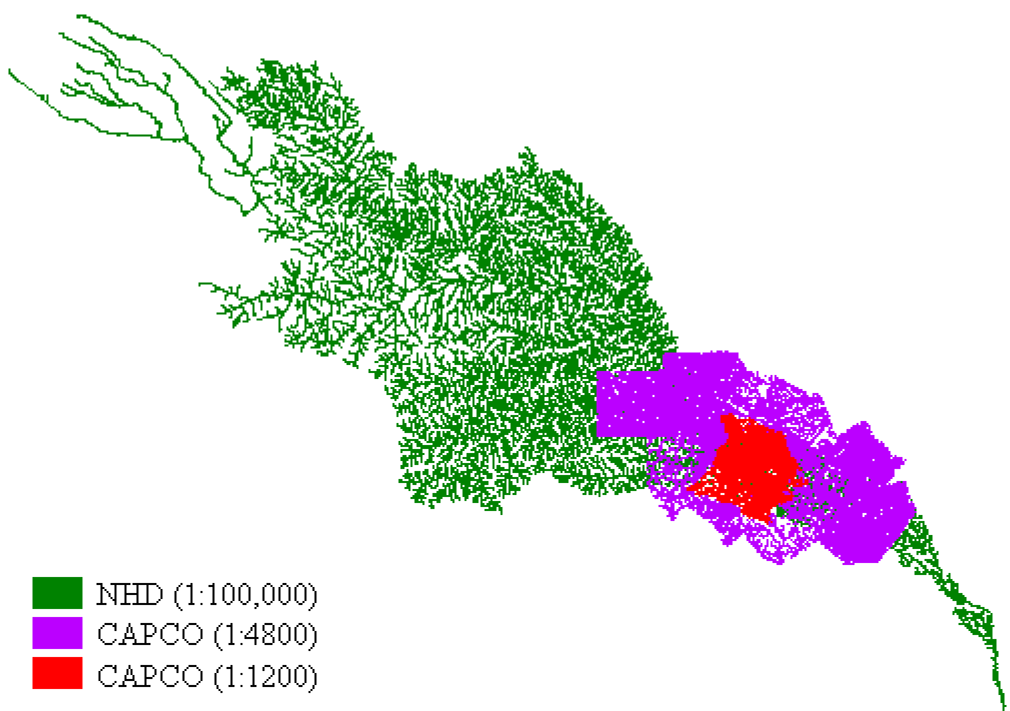



Figure 3.1. Extent of three sources of creeks data

As can be seen from Figure 3.1, the NHD covers the widest area of land, while the 1:4800 scale CAPCO data covers only selected counties, and the 1:1200 scale CAPCO data covers only the Austin, Texas area.

#### *3.1.1.3 LCRA Stationing Line*

Richard Diaz of the LCRA used 1:12,000 Digital Orthophoto Quarter Quadrangles created for the Texas Orthoimagery Program to digitize a file (*coloriv_cl*) of the Colorado main stem downstream of Stacy Dam. According to Mr. Diaz, the shapefile is considered the most accurate representation of the location of the Colorado main stem that the LCRA has. The line follows the part of the river that is darkest in color on the DOQQ, since this is a close approximation to the deepest part of the river. In areas where the darkest color technique was not useful, the line was placed in the center between the two banks. In the large lakes, where bathymetric lake bottom elevation data is available, the line follows the deepest part of the lake.

#### *3.1.1.4 Waterbodies and Banks*

Waterbody and bank locations were used for graphics in maps, for locating important points of interest within the basin, for preliminary studies of accounting for lake boundaries during watershed delineation, and for channel cross-section extraction. The waterbody outlines relied on were 1:100,000 scale EPA files (LCRA, 1993). The bank locations were digitized from 1:16,800 scale aerial photographs taken by ADR, Inc. for the LCRA between February of 1998 and February of 1999 (ADR, 2001).

### 3.1.2 Digital Raster Graphics

The digital raster graphics used in this study were georeferenced digital maps or photos placed under other shapefiles to allow manual checking of features in areas of editing.

#### *3.1.2.1 USGS Digital Orthophoto Quarter-Quadrangles*

The USGS began producing Digital Orthophoto Quadrangles (DOQs) in 1991 and is expected to complete production for the entire United States by 2004 (USGS, 1998). The USGS orthophotos used for the LCRA study each covered 3.75 minutes of latitude by 3.75 minutes of longitude, one quarter the size of a DOQ, and were called Digital Orthophoto Quarter-Quadrangles (DOQQs). The DOQQs meet horizontal National Map Accuracy Standards at a 1:12,000 scale, and have a ground sample distance of one meter (USGS, 1996). A USGS digital orthophoto quarter-quadrangle showing a portion of Lake Travis is pictured in Figure 3.2.

Figure 3.2. USGS digital orthophoto quarter-quadrangle

#### *3.1.2.2 USGS Digital Raster Graphics Quadrangles*

Between 1995 and 1998 the USGS electronically scanned its paper 1:24,000 scale topographic maps and called the maps in digital form digital raster graphics (DRGs) (USGS, 2000). DRGs were used in the LCRA study for the information they could provide in addition to DOQQs, and in place of DOQQs in areas where the DOQQs were not available. A USGS digital raster graphic is pictured in Figure 3.3.

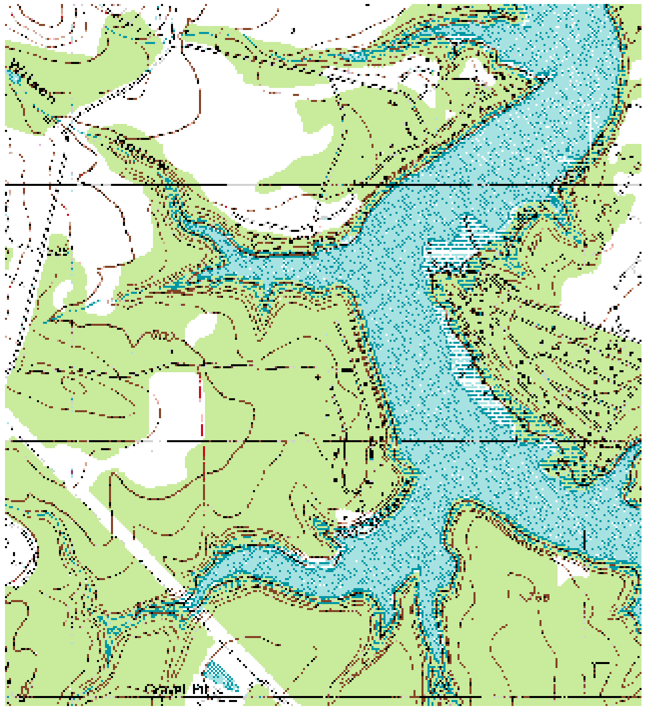


Figure 3.3. USGS digital raster graphic

### 3.1.3 Watershed Outlet Locations

Various sources of data were used for location of outlets from which to delineate watersheds. Development of sets of watershed outlet points from the data is discussed in Section 5.2.1.

#### *3.1.3.1 8-digit Hydrologic Cataloging Units*

The USGS hydrologic cataloging units are a set of 2150 watershed polygons covering the United States delineated at a 1:250,000 scale in the 1970s (USGS, 1995). Each cataloging unit has a unique 8-digit Hydrologic Unit Code (HUC) that is often used as part of a feature's hydrologic address, such as the reach codes in the NHD. Since the hydrologic cataloging units are so widely used, the intersections between cataloging unit boundaries and streams were deemed important enough to be locations for watershed outlets.

The 26 8-digit HUCs in the Colorado River Basin in Texas can be seen in Figure 3.4 below. Thirteen of these, outlined in pink, are inside the LCRA study area.

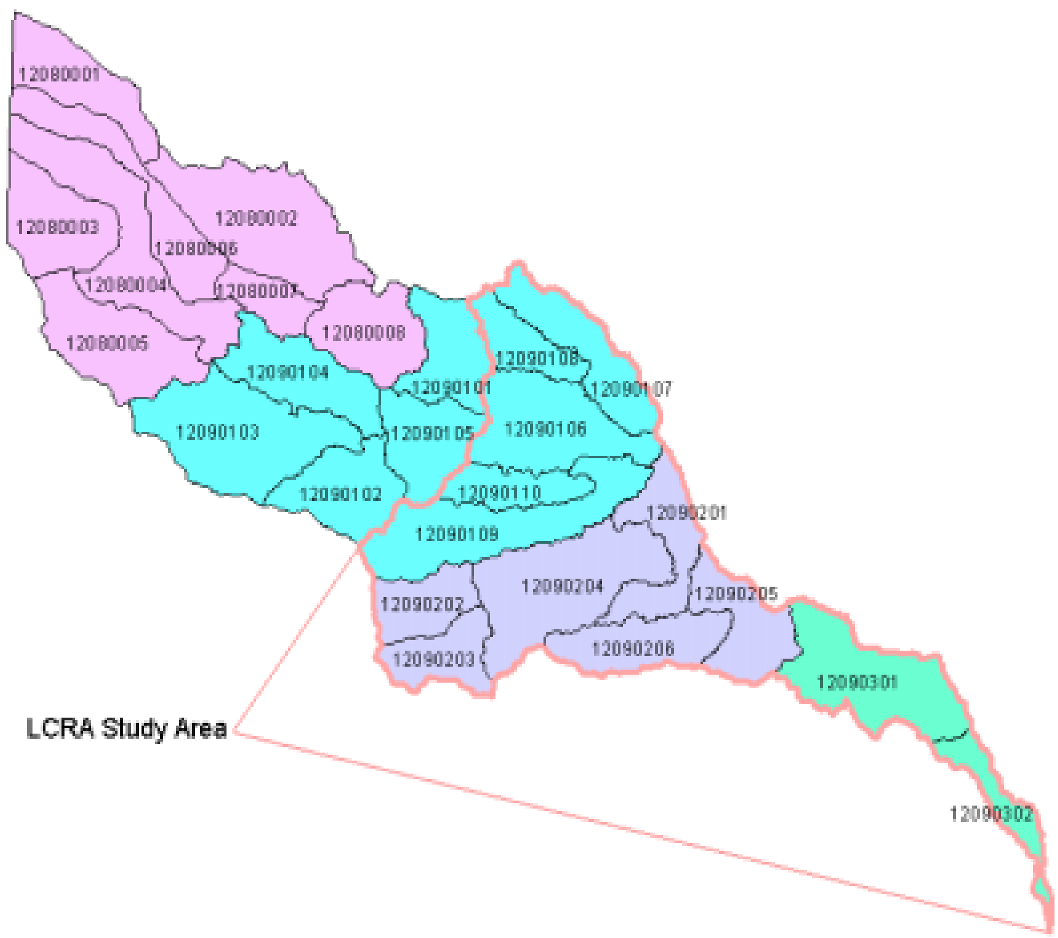



Figure 3.4. 8-digit HUCs in the Colorado River basin, shaded by 6-digit HUC

#### *3.1.3.2 LCRA Proposed and Existing Gages*

The locations of the LCRA's proposed and existing flow gages are constantly evolving. The set of gage locations used for this study came from a file (*hydromet_ut_07_06_2000.shp*) created at the LCRA, which contains all the existing and proposed LCRA gage locations as of July 6, 2000. Seventy-five gages remained in this data set after it was edited to remove duplicate gages and gages not on the stream network.

#### *3.1.3.3 TxDOT Roads Coverage*

Bridge locations were used as watershed outlets in the most detailed of the watershed delineations done in this study. The 1213 bridge locations came originally from the Texas Department of Transportation (TxDOT) roads coverage. The TxDOT roads coverage was digitized from USGS 1:24,000 topographic map quadrangles, and some areas were updated with TxDOT highway construction plans, aerial photographs, official city maps and field inventory data (TxDOT, 1998).

### 3.1.4 Digital Elevation Data

The USGS National Elevation Dataset (NED) provided the elevation data grid used for watershed delineation. The NED is a set of Digital Elevation Models (DEMs) for the United States with a scale of 1:24,000 and a resolution of 1x1 arc-second, or approximately 30x30 meters. The vertical elevation measurements are floating point, in meters (USGS, 1999). The processing done on the elevation data to prepare it for watershed delineation is discussed in general in Section 4.3 and more specifically in Section 5.2.1.

### 3.1.5 Land Cover and Soils Data

#### *3.1.5.1 LCRA Land Cover*

The 1997 land cover data that was used for parameter calculation in the study was created by EISYS for the LCRA. The data is recommended for use in applications needing a scale between 1:80,000 and 1:100,000 and never less than 1:40,000. Each grid cell contains a value representing one of the land cover categories listed in Table 3.1 (EISYS, 1998).

Table 3.1. LCRA 1997 Land Cover Codes

| Land Use Code | Land Use |
|---|---|
| 0 | No Data |
| 3 | High Intensity Urban |
| 4 | Low Intensity Urban/Rural Developed |
| 5 | Golf Courses and Parks |
| 10 | Cultivated Lands |
| 11 | Cultivated Lands - Flooded |
| 20 | Grasslands |
| 28 | No Data |
| 32 | Broad-leaved Deciduous Forest |
| 36 | Cedar |
| 37 | Pine Forest |
| 39 | No Data |
| 44 | No Data |
| 47 | No Data |
| 48 | Woodland/Shrubland |
| 49 | No Data |
| 50 | Bare Lands |
| 60 | Wetlands |
| 61 | Unconsolidated Shore |
| 64 | Saline Emergent Wetlands |
| 65 | Saline Woody Wetlands |

| | |
|---|---|
| 66 | Fresh Emergent Wetlands |
| 68 | Fresh Woody Wetlands |
| 70 | Water and Submerged Lands |

#### *3.1.5.2 National Land Cover Dataset*

The National Land Cover Dataset (NLCD) was used as a substitute for the 1997 LCRA land cover dataset in areas not covered by the LCRA land cover dataset. The combining of the two grids is explained in Section 5.3.1. Table 5.1 contains the land use codes for the final combined land cover data set.

The NLCD was made available for most of the United States in the fall of 2000. The classifications are based mainly on the Multi-Resolution Land Characteristics Consortium Landsat 5 Thematic Mapper satellite data. The data is at a 30-meter resolution. The land classification categories for the NLCD and their codes are listed in Table 3.2 (USGS, 2000).

Table 3.2. NLCD Land Cover Codes

| **Land Use Code** | **Land Use** |
|---|---|
| 0 | No Data |
| 11 | Open Water |
| 12 | Perennial Ice/Snow |
| 21 | Low Intensity Residential |
| 22 | High Intensity Residential |
| 23 | Commercial/Industrial/Transportation |
| 31 | Bare Rock/Sand/Clay |
| 32 | Quarries/Strip Mines/Gravel Pits |
| 33 | Transitional |
| 41 | Deciduous Forest |
| 42 | Evergreen Forest |
| 43 | Mixed Forest |

| | |
|---|---|
| 51 | Shrubland |
| 61 | Orchards/Vineyards/Other |
| 71 | Grasslands/Herbaceous |
| 81 | Pasture/Hay |
| 82 | Row Crops |
| 83 | Small Grains |
| 84 | Fallow |
| 85 | Urban/Recreational Grasses |
| 91 | Woody Wetlands |
| 92 | Emergent Herbaceous Wetlands |

#### *3.1.5.3 STATSGO Soils*

Soils data were used along with land cover data to calculate initial and constant infiltration rates for each watershed, as explained generally in Section 4.4 and more specifically in Sections 5.3.2.3 and 5.3.2.4. The 1:250,000 scale State Soil Geographic (STATSGO) soils database was used for this purpose. The data comes from generalizing more detailed paper maps developed by the National Cooperative Soil Survey (U.S. Department of Agriculture, Soil Conservation Service, 1994).

## 3.2 MAP PROJECTIONS AND MEASUREMENT UNITS

The map projection for all deliverables in this study was selected because it is the standard projection used for all work at the LCRA. The projection is State Plane, Texas Central Zone, North American Datum of 1983, Geodetic Reference System 80 ellipsoid, with map units in feet.

Since CRWR-PrePro must use meters when calculating certain watershed attributes, much of the processing was done in State Plane, Texas Central Zone, North American Datum of 1983, Geodetic Reference System 80 ellipsoid, with map units in meters. Processing in HEC-GeoHMS was done with map units in meters as well, so that the same grids could be used for all processing without reprojection. Shapefiles that were processed in meters were projected to feet before delivery to the LCRA or to Halff Associates, Inc. Grid processing was done completely in meters and the grids were not re-projected to feet.

# CHAPTER 4: TOOLS AND METHODS

## 4.1 GEOGRAPHIC INFORMATION SYSTEMS

Geographic Information Systems (GIS) were used to do all of the data processing described in this thesis. Although there are many different definitions of GIS, it can be thought of as a computer system for storing, viewing, editing or analyzing geographically referenced data. GIS is used for many purposes, such as traffic planning, water and electric utility design, and law enforcement. It is an important tool in water resources engineering because of the spatial nature of water resources problems.

ArcView 3.2, Workstation ArcInfo 7.x, and ArcGIS 8.1, developed by the Environmental Systems Research Institute, Inc. (ESRI), are the GIS software packages used for this project. Other scripts and extensions used were created to be compatible with the ArcView, ArcInfo and ArcGIS 8.1 systems. ArcView provides a visual environment for viewing and manipulating data in intuitive ways. Workstation ArcInfo provides the user with only a command box to look at along with a set of powerful commands that can be used to analyze and modify data. ArcGIS 8.1 includes the programs ArcCatalog and ArcMap that are used jointly. ArcCatalog is for storing and organizing data, and is used to import the data into personal geodatabases in which all the data layers in a project can be stored and manipulated concurrently. ArcMap is a graphical environment with functionality that combines the capabilities of ArcView and ArcInfo. In this project, ArcView 3.2 was used for work with grids and shapefiles, Workstation ArcInfo was used for work with grids and coverages, and ArcGIS was used for work with shapefiles, coverages, and feature classes.

The ArcGIS Hydro Data Model is a framework in ArcGIS for manipulating and storing data related to hydrology and hydraulics. Feature classes in ArcGIS are organized within feature datasets. The ArcGIS Hydro Data Model contains 4 feature datasets, Drainage Areas, Hydro Features, Hydro Network, and Channels. The points, lines, and polygons shapefiles constructed for this project were loaded into the data model as a trial of the data model during its development. When the data model is fully developed, the LCRA plans to adopt it as a way to organize their data storage and procedures for the basin flood work.

## 4.2 LINEAR REFERENCING

Linear referencing along every stream in the network was accomplished using ArcCatalog, ArcMap, and a combination of custom scripts contained in the ArcHydroTools toolbar written by Tim Whiteaker. The toolbar is shown in Figure 4.1. The process requires the streams to be stored as a feature class in a personal geodatabase, the ArcGIS 8.1 way of storing data. Within the geodatabase, a network is built that defines the connectivity of the streams. An outlet is created at the most downstream point, and flow direction towards this outlet is set.

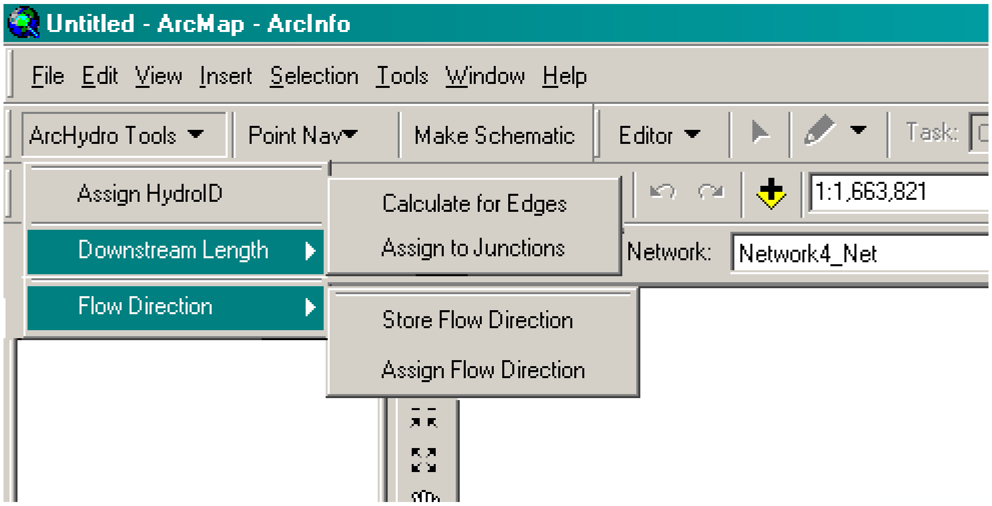



Figure 4.1. ArcHyro Tools menu options

An attribute of the stream network called FlowDirection is populated using the “Assign Flow Direction” tool within ArcHydroTools with either a 1 for “with digitized”, a 2 for “against digitized”, or a 3 for “indeterminate”. Each reach in the network has two directions, the direction in which the reach was digitized and the network flow direction towards the sink. The script compares the network flow direction of each reach to the direction in which the reach was digitized and populates the attribute field with the result. A flow direction attribute is necessary because measure calculations are based on the reach’s direction of digitization, which is frequently arbitrary.

A second attribute, ShapeLength, is populated automatically when the streams are imported into the geodatabase with each line’s length in map units.

A third attribute, LengthDownstream, is populated by the “Calculate Downstream Length for Edges” tool within ArcHydroTools. For each reach, the lengths of all the reaches downstream are totaled by summing the ShapeLength attribute, and the sum is placed in LengthDownstream.

The streams in the geodatabase are a type of polyline called PolylineM, which contains an x, y and m coordinate at each vertex, allowing the assignment of a measure value to each vertex. After the FlowDirection, ShapeLength, and LengthDownstream attributes were populated, m-values were assigned to every vertex by doing a calculation on the Shape attribute. The measures of each reach were interpolated between the LengthDownstream and the (ShapeLength + LengthDownstream). The interpolation was done in the opposite direction if the FlowDirection field indicated that the flow direction was against the digitized direction. This interpolation can be done in a few other ways as well. For example, an interpolation between 0 and 100 yields a percent distance along the reach, resulting in a relative measure instead of an absolute measure. An interpolation between zero and ShapeLength yields absolute measures starting from zero at the bottom of each reach.

The linear referencing procedures employed for this project are discussed in more detail in section 5.1.5, with additional discussion in section 6.2.

## 4.3 WATERSHED DELINEATION

Watersheds were delineated using a combination of ArcInfo Grid, a grid manipulation program that is part of Workstation ArcInfo, and CRWR-PrePro, a set of ArcView scripts developed by researchers at CRWR that take advantage of the functionality of ArcInfo Grid for the purpose of watershed delineation and hydrologic model creation. The method used for watershed delineation in ArcInfo Grid is the same as that used by CRWR-PrePro.

The procedure, as described by Olivera and Maidment (1999), begins with a vector stream network, a DEM and a set of desired watershed outlet points. The result is a set of watersheds delineated from these points and a new stream network based on a combination of the vector stream network and the DEM.

The first step is to change the vector stream network to a grid, as depicted in Figure 4.2.

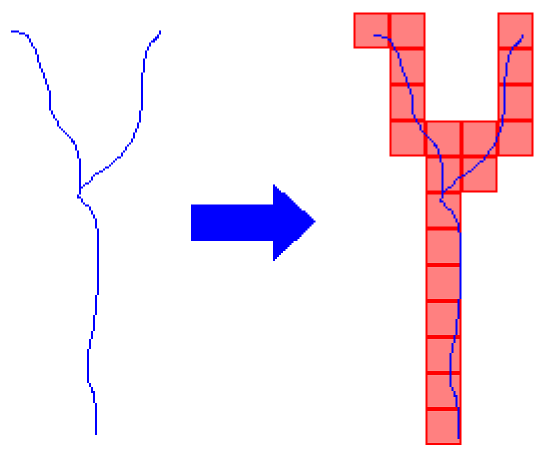


Figure 4.2. Creation of initial stream grid from vector streams

The grid cells in the stream grid must be set to exactly the same sizes and locations as those of the DEM. If each cell in the stream grid has boundaries exactly coincident with the DEM cell boundaries, then the two grids can be manipulated together.

Each of the cells in the stream grid is initialized with a value of one and then multiplied by the value of the Dem cells underneath it. This produces a stream grid with elevations.

The stream grid with elevations is used to “burn” the streams into the DEM. First, a large number such as 1000 meters is added to each DEM cell, then this DEM is merged with the stream grid with elevations. The original elevations replace the magnified elevations where there are streams, producing an elevation grid that is the same as the original DEM except with a large number added to the elevation in cells with no streams.

Next, the burned DEM is filled. Any inconsistencies in the data that would cause one of a few cells to be a bit lower than the ones surrounding them, thus creating a “sink” that does not exist in real life, are removed.

A flow direction grid is created from the filled DEM. From each grid cell, water is assumed to flow to one of the 8 surrounding cells. It flows to the cell for which a line between the centers of the two cells has the steepest slope based on the difference in cell elevations. The value shown in Figure 4.3 is given to each grid cell to specify in which direction water in this cell flows.

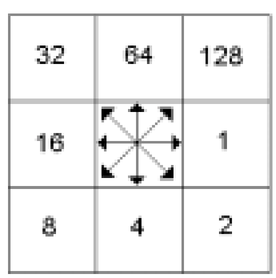



Figure 4.3. Numbers assigned to grid cells based on flow direction

A flow accumulation grid is created from the flow direction grid. The value of each cell in the flow accumulation grid is the number of cells that drain into that cell from upstream.

A new DEM-derived stream network is created from the flow accumulation grid. The new stream network is similar to the one created by rasterizing the original vector stream network. The major difference is that streams are defined based on a steam drainage threshold in the flow accumulation grid rather than on a cartographic delineation. If a cell has more than the threshold number of cells draining to it, it is a stream, regardless of where the streams were originally burned into the DEM. After the DEM-delineated stream network is vectorized, it appears jagged as in Figure 4.4, with a stream configuration slightly different from the vector stream network used for its creation.

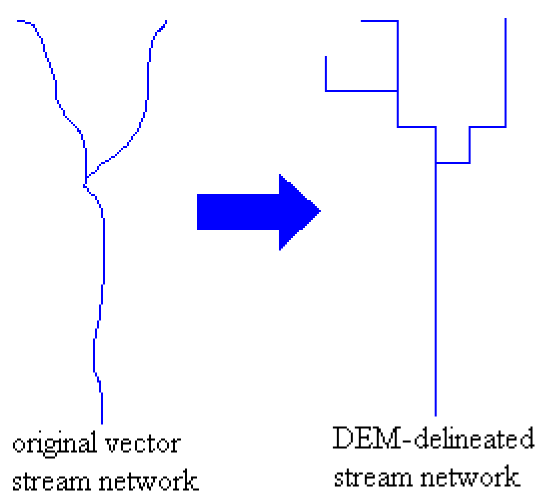



Figure 4.4. Comparison of DEM-delineated streams to original vector streams

The new raster stream network is transformed into a set of links. Links are defined by giving each reach between two stream confluences a unique identification number called a grid code.

CRWR-PrePro was used to create an outlet grid from stream confluences, a vector points file, or both. The set of outlets selected determines whether the delineation is of catchments or watersheds. Catchments have outlet points selected on some systematic, reproducible basis. Watersheds have outlet points that can be selected for any reason. In this study, the furthest downstream cell of each link is an outlet for a catchment, with a 2878 cell drainage threshold to define a link. This definition of a catchment produces a one to one ratio between links and catchments. Outlets of watersheds are placed based on gage and bridge locations; watershed shape and size; and importance of certain rivers or confluences. Figures 4.5 and 4.6 show examples of catchments and watersheds as they were defined for this study.

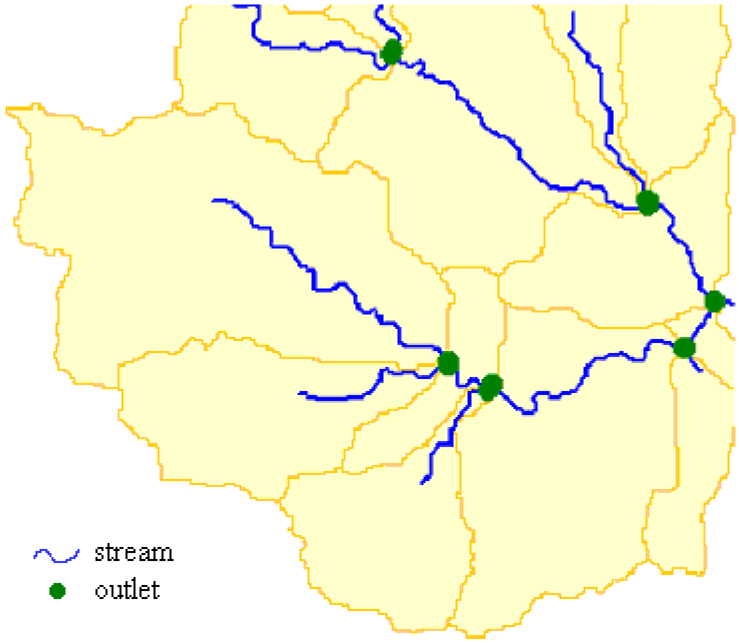



Figure 4.5. Catchments as they were defined for this study

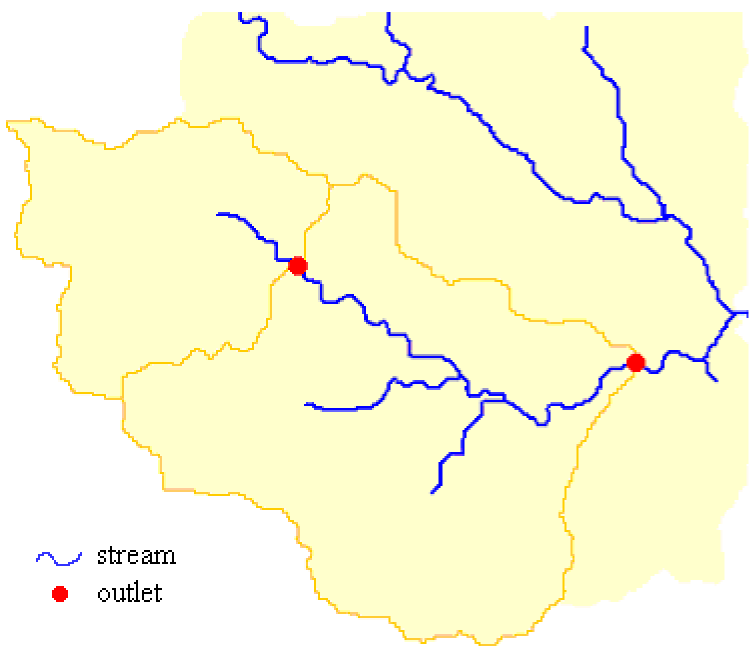



Figure 4.6. Watersheds as they were defined for this study

Watersheds are delineated using CRWR-PrePro version 3a, based on the outlet grid, the stream network, and the flow direction grid. The raster watershed boundaries and stream network are then vectorized to make them easier to work with. CRWR-PrePro's menu options, including the functions for watershed delineation, can be seen in Figure 4.7.

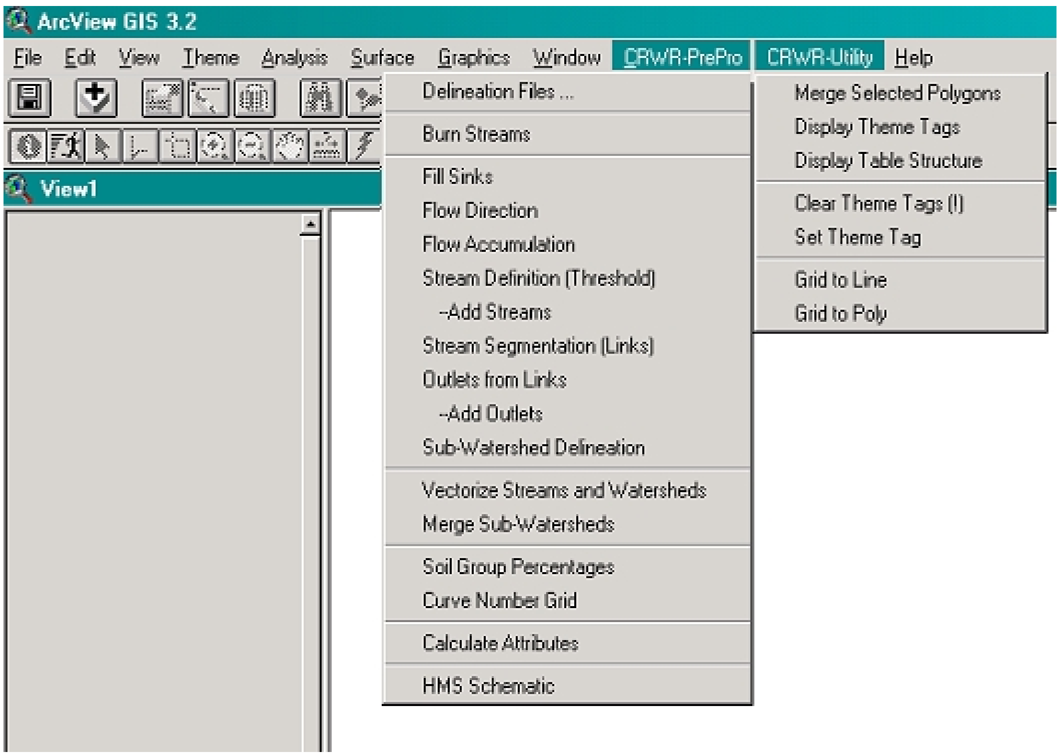



Figure 4.7. Menu options of CRWR-PrePro

The watershed delineation process used for this project is discussed further in Section 5.2 with descriptions of each specific processing step taken. The results of the watershed delineation are presented in Section 6.3.

## 4.4 HYDROLOGIC ATTRIBUTE CALCULATION

Attributes were calculated for each watershed in support of the modeling planned on these watersheds. All attributes were determined based on basin-wide GIS data. Initial and constant losses were determined in support of planned runoff prediction. The Soil Conservation Service curve number method was used to estimate initial loss. A set of parameters consisting of flow paths, slopes, percent urbanization, and percent impervious cover was also determined to support the Snyder's Unit Hydrograph transform method.

CRWR-PrePro contains many functions for attribute calculation. In this study, the most essential of those contained in CRWR-PrePro were the functions used to determine the initial and constant loss rates. These functions, "Soil Group Percentages" and "Curve Number Grid", are visible in Figure 4.6. The process begins with a land cover grid containing classification such as grasslands and high intensity urban; soils polygons each with a hydrologic classification of A, B, C, or D depending on drainage properties; and lookup tables that specify a curve number or uniform loss rate for each possible combination of land cover and hydrologic soil group. The land cover codes from the two original data sources and their meanings are available in Tables 3.1 and 3.2, the land cover codes in the merged and edited land cover grid used for parameter calculation are in Table 5.1, and the curve number and uniform loss rate lookup tables are in Appendix A in Tables A.1 and A.2.

The soil polygons are divided into larger units called map units. The Soil Group Percentages function in CRWR-PrePro is used to create a table of percentages of each hydrologic soil group in each map unit.

The Curve Number Grid function in CRWR-PrePro is used to intersect the soil map units with the land use polygons. For each polygon created by the intersection, a curve number or constant loss rate is calculated for that land use and set of soil group percentages, based on the lookup table. These polygons are converted to a grid with a cell size specified by the CRWR-PrePro user before they are returned. The entire process for curve number grid creation is diagrammed in Figure 4.8, and explained further in Sections 5.3.1 and 5.3.2.3.

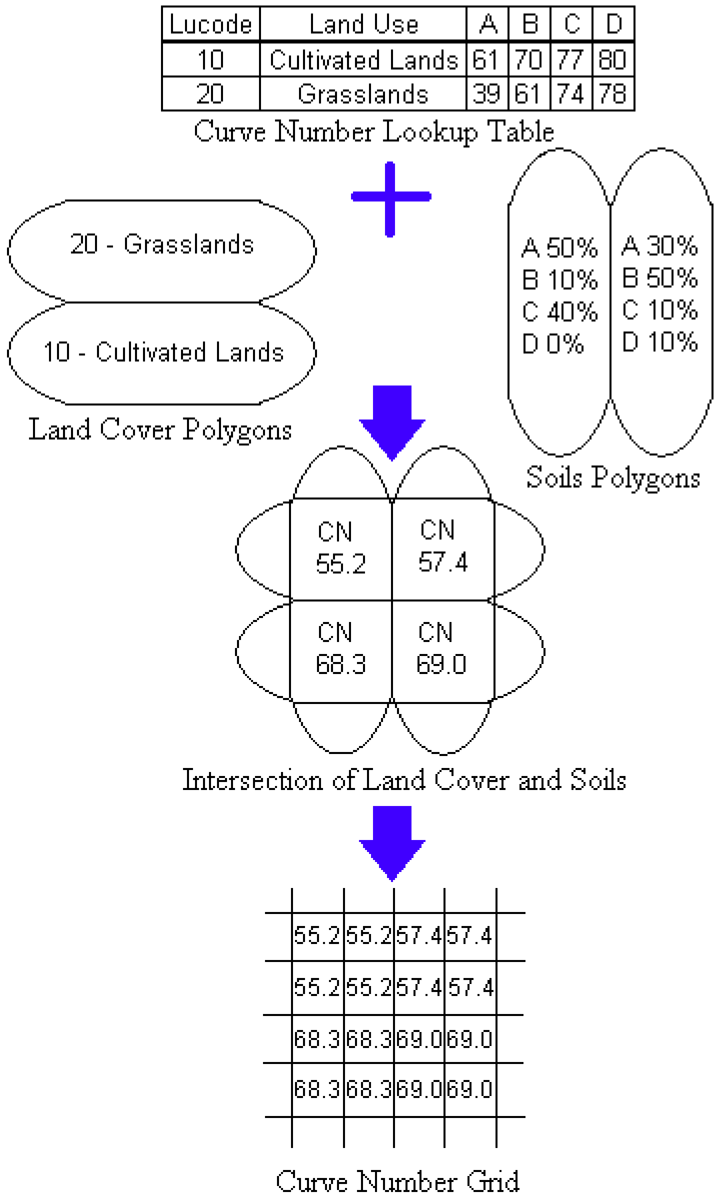



Figure 4.8. Process for creation of curve number grid

The same method with a different lookup table is used for calculation of a constant loss rate grid, as is explained more specifically in Section 5.3.2.4.

The ArcView extension developed by Francisco Olivera, CRWR Raster (Figure 4.9), contains a command that averages a grid value on a set of polygons. This command was used on the curve number grid and constant infiltration rate grid to compute a weighted average of the grid values on each of the watershed polygons, populating the attribute for each watershed with its average value.

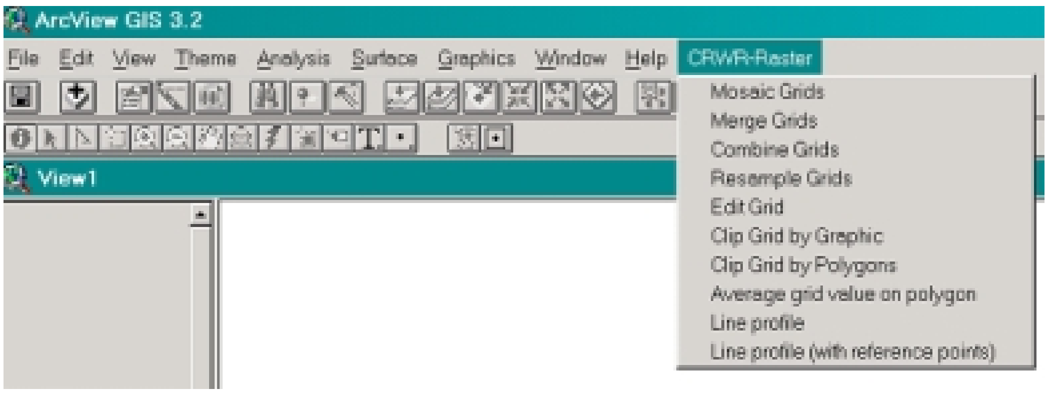



Figure 4.9. Menu options of CRWR Raster

Most of the Snyder's Unit Hydrograph parameters were calculated using HEC-GeoHMS, a successor to CRWR-PrePro with similar functionality developed by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 2000). These calculations, done for each watershed, include length of the main channel flow path, length of the main flow path from the discharge point to a point opposite the centroid, and the average slope of the main channel between points located at 10 and 85 percent of flow. HEC-GeoHMS was used because of its tool for calculating slope between points located at 10% and 85% along the length of the longest flow path. CRWR-PrePro currently calculates slope between points located at 1% and 99% of the flow length, and would have required a modification to change to 10% and 85%.

Figure 4.10 shows the “Basin Characteristics” menu in the Project View of HEC-GeoHMS, which contains the functions that were used.

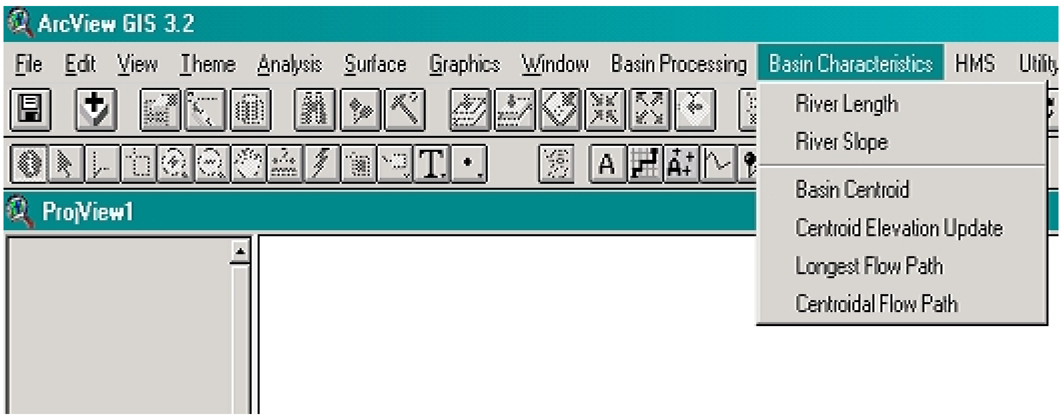



Figure 4.10. Basin Characteristics menu of HEC-GeoHMS

The other two parameters supporting the Snyder’s Unit Hydrograph method, percent urbanization and percent impervious cover, were calculated using ArcInfo commands followed by CRWR Raster’s average grid value on polygon command. In Section 5.3.2, the specific parameter calculation operations used in this project are discussed.

## 4.5 HEC-HMS SCHEMATIC CREATION

Watershed information from GIS can be used in HEC-HMS modeling by transforming the necessary data into the correct format for import into HEC-HMS, the HEC-HMS basin file. A basin file is a text file listing each sub-basin, reach, reservoir, junction, source or sink. For each of these elements, there is an element type, hydrologic parameters, and a downstream element (Olivera and Maidment, 1999). CRWR-PrePro was used to transform the watershed polygons and their attributes to an HEC-HMS basin file. CRWR-PrePro's attribute transfer capabilities were used to transfer attributes from the watershed attribute tables to the basin file, so they could be read by HEC-HMS. Details of the HEC-HMS schematic creation procedure are explained in Section 5.4. Additional discussion of the preliminary hydrologic model follows in Section 6.4.

A map file was created from the vectorized watersheds and streams using an ArcView script called "hmsmap" written by Joaquim Pinto da Costa and modified by Francisco Olivera in 1998. When the map file is opened in HEC-HMS, it shows outlines of each watershed and traces of the streams. This makes it possible to see the watershed shapes and stream locations while working in HEC-HMS, greatly increasing the ease of use of the hydrologic model.

# CHAPTER 5: PROCEDURE

A single line river network was created from multiple data sources. The centerline was attributed with NHD reach codes and every vertex in the network was given a measure value to support linear referencing. Watersheds were delineated based on the vector stream network and DEMs. Hydrologic attributes were calculated from basin-wide GIS data, and the watershed topology and attributes were transferred to an HEC-HMS basin file.

## 5.1 PREPARATION OF SINGLE-LINE NETWORK

The single line river network was first compiled from the National Hydrography Dataset. The initial NHD network was edited to make it useable. The accuracy in certain locations important for modeling was improved through use of multiple additional data sources. The Colorado River centerline was prepared for use as a stationing line by attributing it with the reach codes from the NHD. Finally, measure values were added to every vertex in the network.

### 5.1.1 Initial Network Construction

NHD data from each of the HUC units were downloaded, with the exception of HUC 12080005, which was not available at the time of download. Since 12080005 is at the upstream edge of the basin in a desert area with very few streams and outside of the LCRA study area, no additional efforts were made to obtain it. The next step was to merge all the reaches in the individual HUC units into one reach file for the entire basin. To do this, all the route.rch files located in the NHD data set were opened in ArcView. The GeoProcessing Wizard contained within the ArcView Geoprocessing extension developed by ESRI was used to merge all the route.rch themes together.

After merging, the new network file was projected from its original geographic coordinates to the projection used for the study. ArcView's Projector! extension developed by ESRI was used to do this. The output units were set to feet, and the projection to State Plane - 1983 datum, Texas Central zone.

### 5.1.2 Fixing Gaps and Loops

Since the river network file at this point was a compilation of many different NHD cataloging unit pieces, there were some gaps and loops in the network that needed fixing. The gaps were fixed with a set of ArcView scripts written by Brad Hudgens, available in a project called "wrap1117.apr" (Hudgens and Maidment, 1999).

The scripts allow the user to click a button called "show dangling nodes" that causes all the dangling nodes in the view to be highlighted. A node is an end of a reach, and a dangling node is an end of a reach that is not connected to another reach. The entire network was examined piece by piece to ensure that the only highlighted nodes were nodes that were supposed to be dangling. If there was a node that needed to be fixed, the "erase interior dangling node" tool in the project connected the gap. The dangling nodes and the two tools used as they appear in the view window of ArcView can be seen in Figure 5.1.

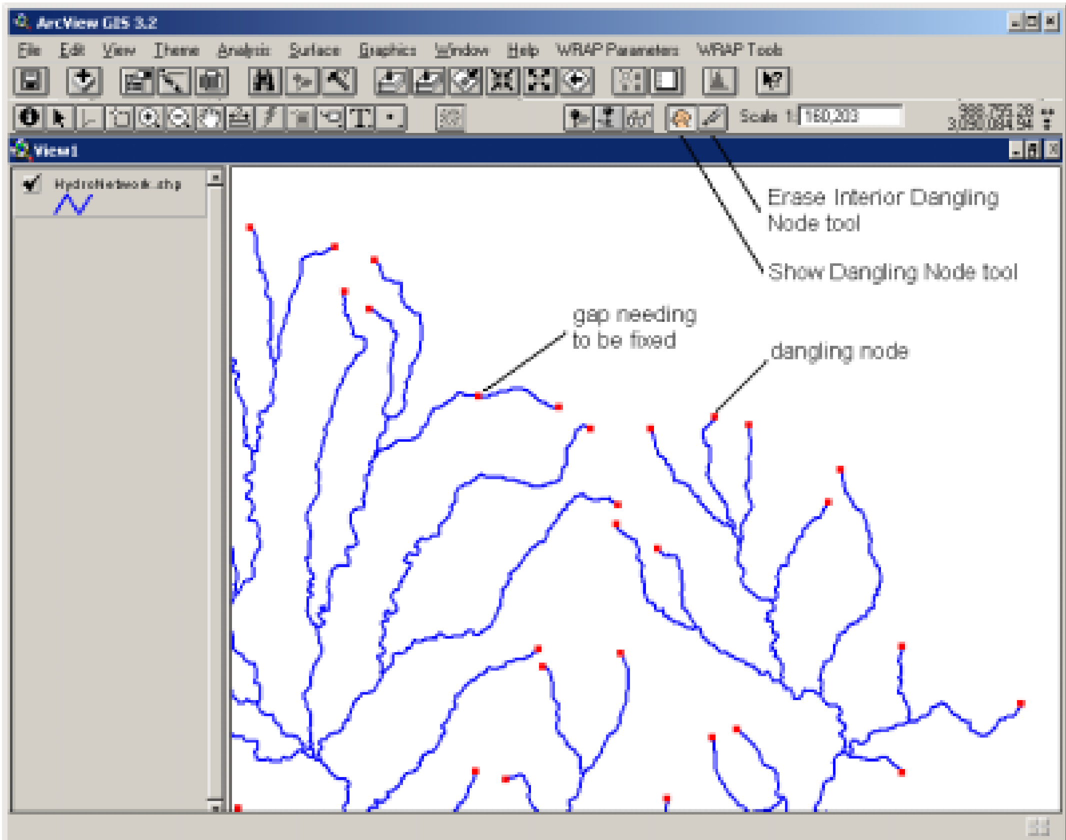



Figure 5.1. Wrap1117 tools for fixing interior dangling nodes

The loops in the stream network were broken because the process used for watershed delineation does not work in a network with loops. The two primary reasons for loops were that the channel was braided or that the flow divided around a small island and rejoined again. It was decided that the shortest flow path, and therefore the path with the steepest slope, would be the most important channel for flood modeling. Looped reaches that were not along the shortest flow path were deleted.

ArcMap, developed by ESRI as part of the ArcGIS 8.1 package, can be used to do a final check for gaps and loops, but since ArcMap was not available at the time the data was prepared, an alternate method is described. First, a temporary ArcInfo coverage of the network was created with the **shapearc** command followed by the **clean** command. The clean tolerance was set to 2, a number low enough to make ArcInfo select the minimum allowable clean tolerance for the data, which was slightly larger than 2.

The following ArcInfo command list adapted from work by Davis (1999) can be used to check for loops in ArcInfo. User-specified file names are in brackets. The result (Figure 5.2) is a shapefile of the loops in the network. Tiny loops can be located in a detailed network by selecting each record in the new polygon shapefile and hitting the "zoom to selected" button in ArcView.

*Arc:* **build <coverage > poly**<br>
*Arcedit:* **arcedit**<br>
*Arcedit:* **ec <coverage_name>**<br>
*Arcedit:* **ef poly**<br>
*Arcedit:* **drawe poly fill**<br>
*Arcedit:* **draw**<br>
*Arcedit:* **selectget**<br>
*Arcedit:* **drawselect**<br>
*Arcedit:* **put <new_coverage >**<br>
*Arcedit:* **quit**<br>
*Arc:* **arcshape <new_coverage > line <new_shapefile >**

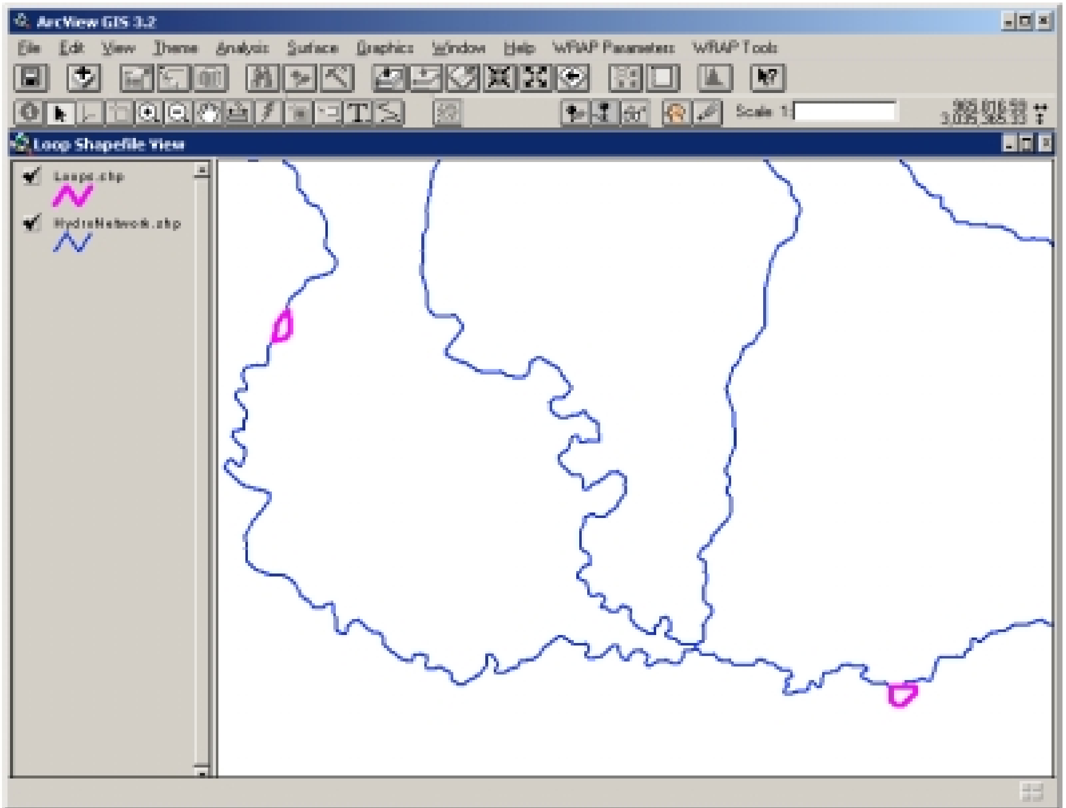



Figure 5.2. Loops identified with a separate shapefile

The last few hard-to-find gaps were located using a trace. A trace is a way of highlighting all the reaches connected to a user-specified point, so that the disconnected reaches show up in a different color than the connected reaches. The set of connected reaches can be converted to a shapefile and overlaid on the original shapefile, making the locations of the gaps more clear. Below is a list of ArcInfo commands to run this trace, adapted from work by Davis (1999). The final result (Figure 5.3) is a shapefile containing only the connected reaches.

*Arc:* **arcplot**
*Arcplot:* **display 9999**

*Arcplot:* **mape <coverage >**
*Arcplot:* **arcs <coverage >**
*Arcplot:* **trace direction <coverage > <upstr> <downstr>**
*Arcplot:* **<click on network outlet point>**
*Arcplot:* **<9>**
*Arcplot:* **quit**
*Arc:* **arcedit**
*Arcedit:* **ec <coverage>**
*Arcedit:* **ef arcs**
*Arcedit:* **setdrawsym 5**
*Arcedit:* **drawe arcs**
*Arcedit:* **draw**
*Arcedit:* **arcplot**
*AP:* **readselect <downstream> clear**
*AP:* **readselect <upstream> or**
*AP:* **quit**
*Arcedit:* **selectget**
*Arcedit:* **drawselect**
*Arcedit:* **put <new_coverage>**
*Arcedit:* **quit**
*Arc:* **arcshape <new_coverage> line <new_shapefile>**

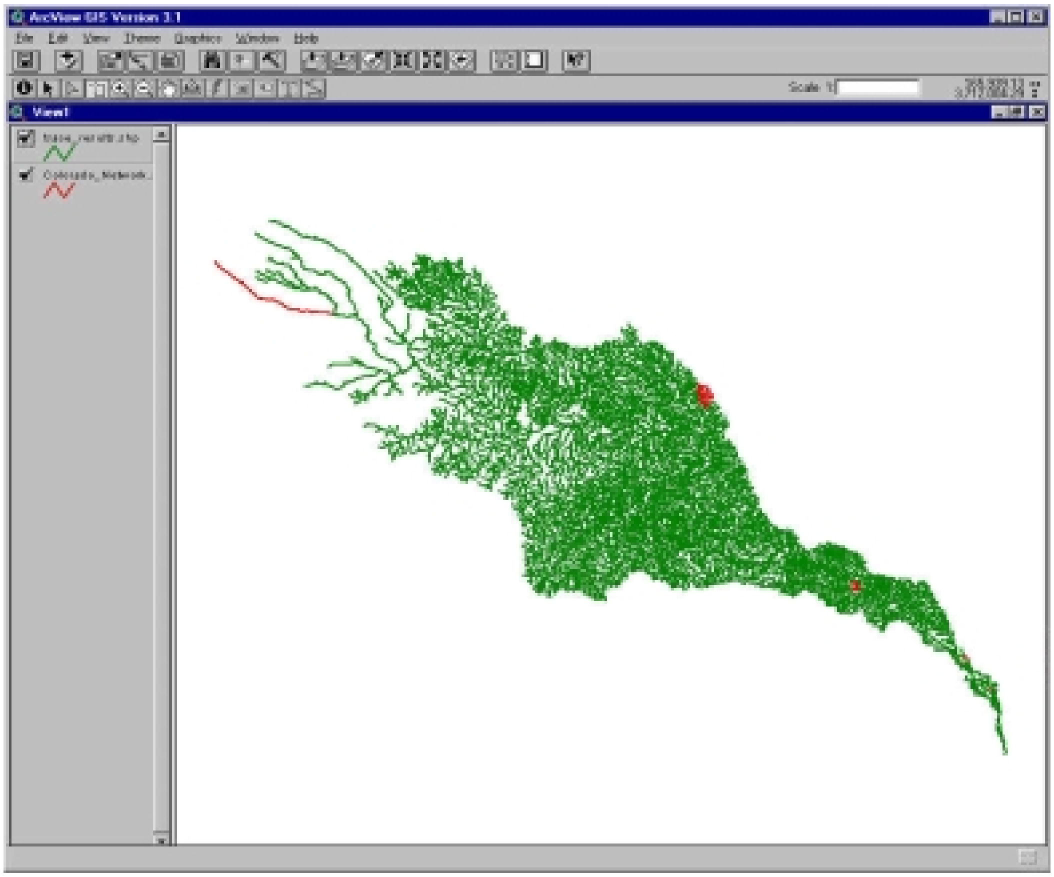


Figure 5.3. A shapefile of the connected reaches (green) and the disconnected reaches (red)

### 5.1.3 Editing Key Reach Locations

It was jointly decided by the LCRA, CRWR and the U.S. Army Corps of Engineers that river flow lines representing reaches should be within 30 meters of the actual physical locations of the reaches in all the river segments where hydraulic modeling might occur. Thirty meters was used as a standard because this is the width of the Digital Elevation Model (DEM) grid cells from the National Elevation Dataset that would be used later for delineating watersheds.

After the streams were burned into the DEM, it would be helpful for the burned DEM to be consistent with any hydraulic models to be created in the future. It was also decided that hydraulic modeling might be done in any reach downstream of one of the LCRA hydromet flow gages, so corrections were necessary to all the reaches downstream of each of these gages. Figure 5.4 shows the reaches, highlighted in green, that were manually edited. The file used to locate the flow gages for this part of the editing process (*hydrm10_26_99*) contains all LCRA flow gages as of October 26, 1999.

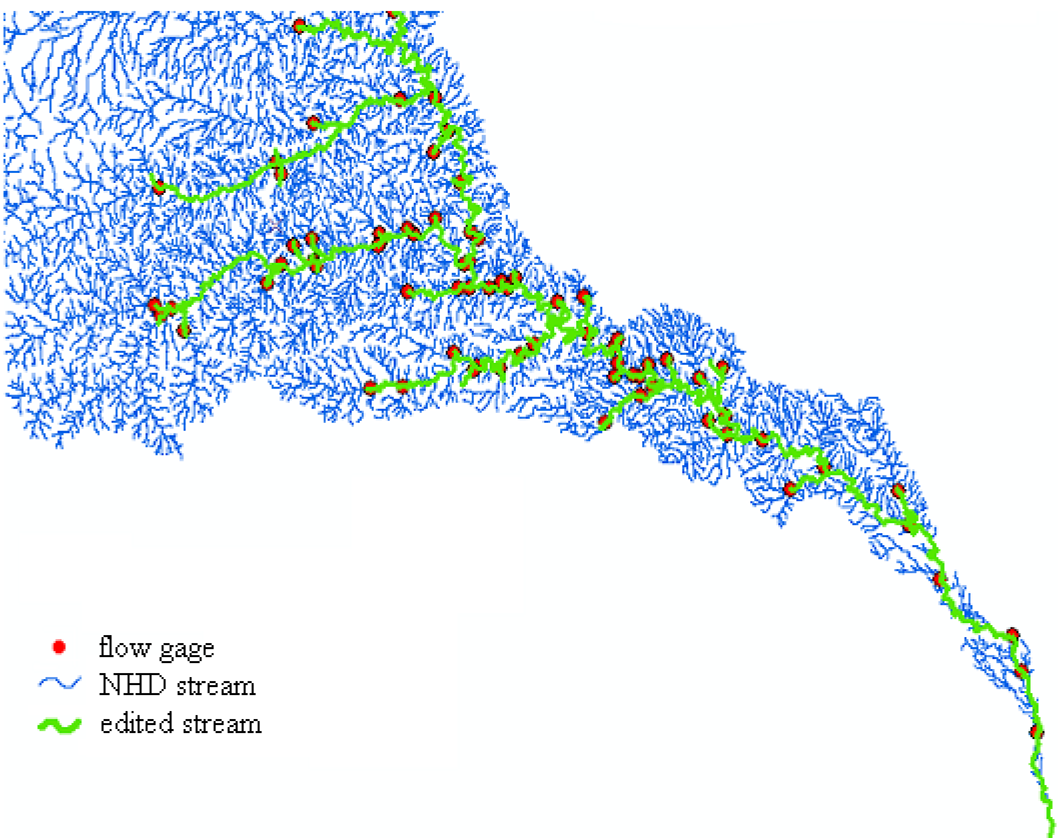



Figure 5.4. Reaches downstream of flow gages were manually edited

Adjusting locations of reaches one by one is a time-consuming process. In order to make the process feasible, some assumptions had to be made. The first assumption was that the one-meter, 1:24,000 Digital Ortho Quarter Quads (DOQQs) display the reaches in their exact physical locations. In a few parts of the river basin, where DOQQs were not available, it was assumed that the digital 1:24,000 USGS maps display the exact physical locations of the reaches. The second assumption was that the line representing a river is sufficiently accurate if the line lies between the banks of the river on the DOQQ. A reasonable attempt was made to place these lines in the center of the river, but having them exactly in the center was not possible or practical. If the line was within the purple region of Figure 5.5, it was considered sufficiently accurate.

Figure 5.5. Highlighted area defines allowable region for edited stream

The Colorado main stem downstream of Stacy Dam in the NHD network was deleted, and was replaced with the LCRA's most accurate representation of the actual river location. The LCRA river location comes from the LCRA file, *coloriv_cl*. Since this was the most accurate and most important stretch of river in the model, the location of this line was not moved at all during any of the corrections that followed. The tributaries that were disconnected because of the removal of the NHD line were each connected with the new centerline by moving and snapping the vertex at the end of each tributary.

If a reach other than the main stem needed to be adjusted and one of the more accurate CAPCO files covered the area, the reach from the NHD network was removed and replaced with the reach from the CAPCO network. Then the NHD tributaries that had been disconnected from the removed NHD reach were reconnected to the new CAPCO reach.

For reaches needing adjustments that were not in the CAPCO counties, the DOQQ was used as a guide for moving or redrawing the NHD reach to relocate it. Moving of the NHD reaches was done by moving the vertices that made up the reach one by one, placing them all over the river's image in the DOQQ. The reach was redrawn by deleting the old reach and then redrawing the new one over the DOQQ. In both cases, tributaries had to be reconnected to the new reaches after the corrections.

In a few areas, the DOQQ was not available. In these areas, the reaches were also corrected by moving their vertices or entirely redrawing, but the USGS DRGs were used as basemaps.

In the correction process, a reasonable attempt was made to maintain as many of the original NHD attributes as possible, but since the presence or absence of attributes does not affect the watershed delineation process, some of the attributes were allowed to be lost.

When all the reaches downstream of gages were corrected, the network was once again checked for gaps and loops. All the gaps were fixed again using the "wrap1117" scripts. The final network (*co_sp83f_0523*) was given to the LCRA as a shapefile.

### 5.1.4 Attributing Reach Codes to LCRA Stationing Line

The engineers at the LCRA and Halff Associates, Inc. selected the Colorado River centerline, *coloriv_cl*, digitized by Richard Diaz of the LCRA, for use as a stationing line. The reach code attribute available from the NHD was chosen as a way to identify locations on the stationing line. Since the line from Richard Diaz did not contain NHD reach codes, a method was developed to attribute the stationing line with the reach codes. The two centerlines were initially divided and attributed as shown in Figure 5.6.

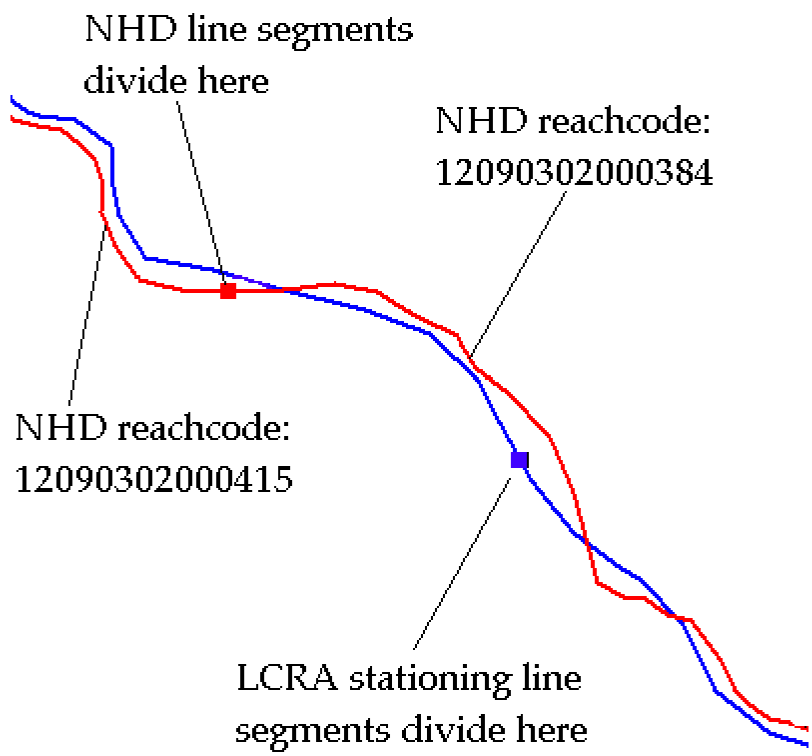



Figure 5.6. Initially the NHD (red) and *coloriv_cl* (blue) are broken in different places

To break the LCRA stationing line in the correct places and transfer the attributes, the first step was to convert the LCRA stationing line (*coloriv_cl*) to an ArcInfo coverage. The NHD Colorado River centerline was separated from its tributaries by manually deleting the tributaries, so that tributaries would not interfere with the process. The **densifyarc** command in ArcInfo was used to break LCRA stationing line every 10 feet. Nodes were added every 10 feet and then **densifyarc** was used to break the arc at each node even though in theory **densifyarc** can be used to break the arc directly without adding the nodes first.

The new breaks in the stationing line allow attributes to be transferred at the correct locations.

The "convert lines to points" tool in the “LCRA Tools” extension in ArcView was used to change the now broken LCRA stationing line to points. The tools available in the extension, developed for the LCRA in July of 2000, can be seen in Figure 5.7

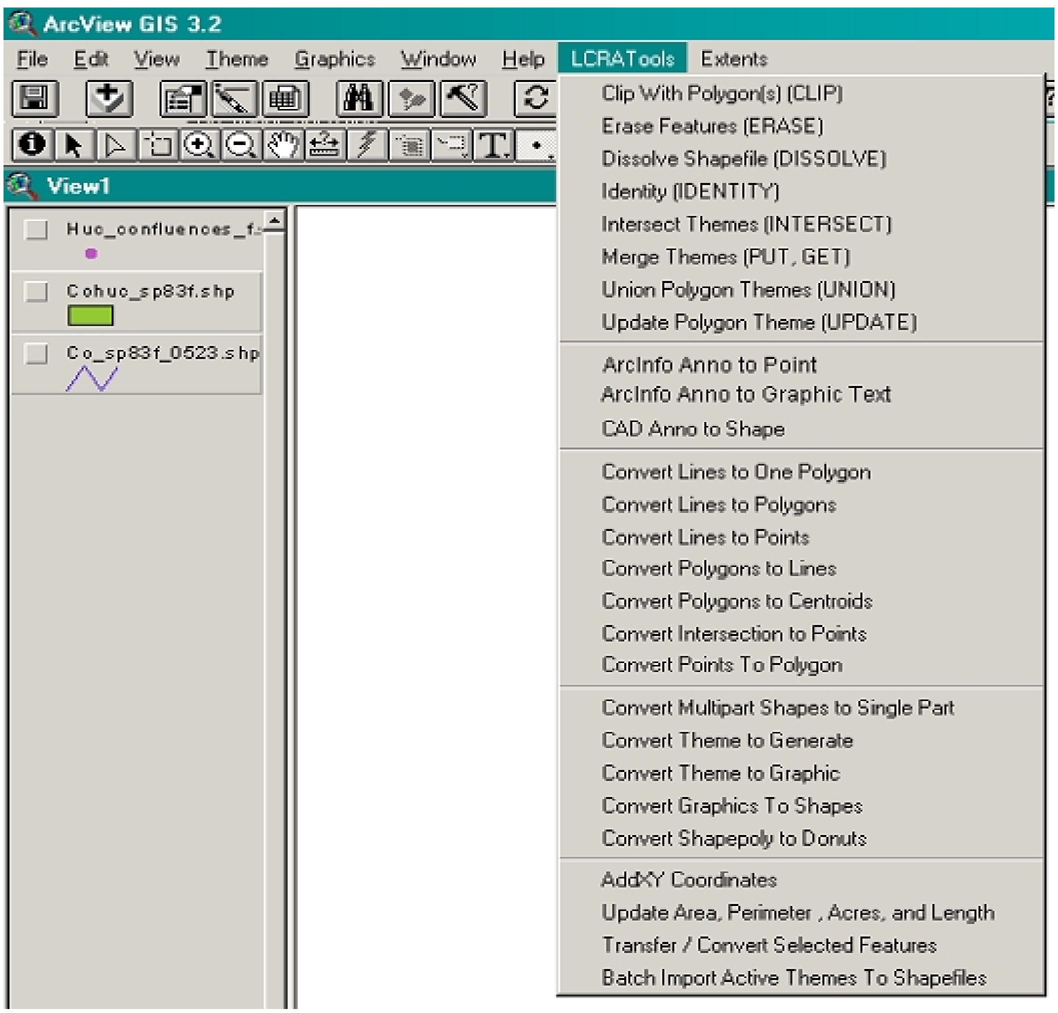



Figure 5.7. LCRA Tools menu options

Converting lines to points makes a point shapefile with a point at each node, vertex, or break in the line. The result is a point lying directly on the LCRA centerline about every 10 feet along it. The "assign data by location" option in the geoprocessing wizard, a tool within the “Geoprocessing” extension in ArcView, was used to assign attributes to each of the new points. The attributes added to each point came from the closest line segment in the NHD centerline file. The "assign data by location" option was used again to assign attributes to each of the 10-foot segments of the LCRA stationing line. The attributes added to each segment came from the closest point in the points file. The attributes had to be transferred from NHD lines to points and then from those points to the LCRA lines since the “assign data by location” tool does not transfer attributes directly from lines to lines.

The broken LCRA centerline coverage with the correct attributes was converted back to a shapefile. The "dissolve features based on an attribute" option in the geoprocessing wizard was used to dissolve the features in the broken LCRA centerline shapefile based on the reach code (rch_code) attribute. This merges the broken pieces back together, making the LCRA centerline broken only where the reach code changes. The result is shown in Figure 5.8.

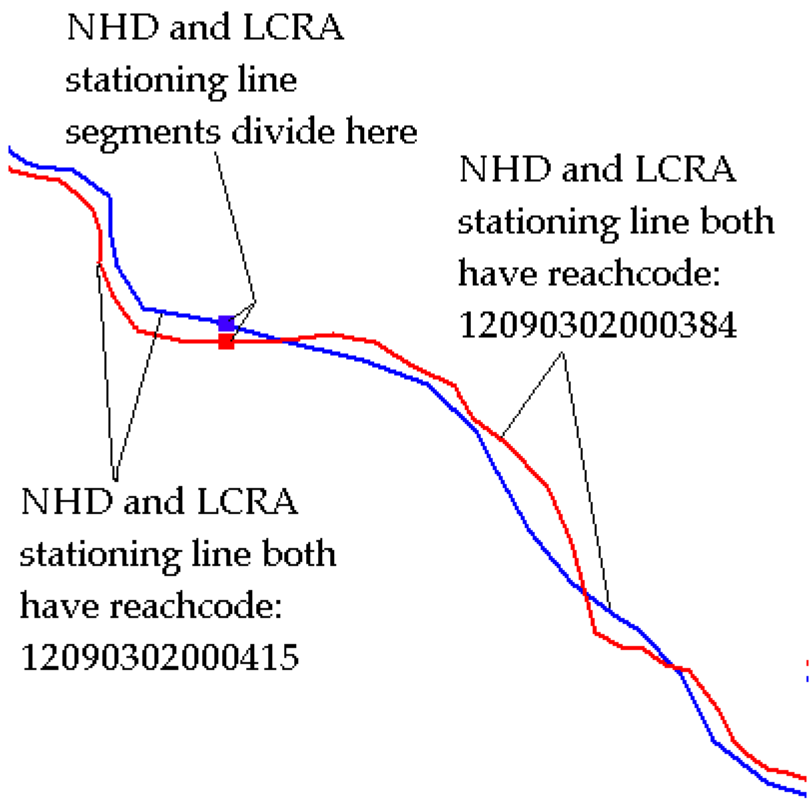



Figure 5.8. *Coloriv_cl* (blue) is broken in new location to allow correct reach code attribution

There are two important warnings about this procedure. In some places the newly attributed stationing line is about four inches ground distance away from the location of the original stationing line, *coloriv_cl*. The probable reasons for this discrepancy are discussed in Section 6.2. The new stationing line file size is about 40 times larger than the original file size. The file is not so large as to be unusable, but if this procedure were employed for a complex network the file size could become impractically large.

### 5.1.5 Linear Referencing

Measures were assigned to every vertex of every stream in kilometers. Each measure is the distance along the network between the vertex and the basin outlet at the Gulf of Mexico. The measures will be used in support of the U.S. Army Corps of Engineers Flood Damage Analysis (FDA) model, a system for calculating flood damage costs based on structure economic values and slab elevations. According to a process developed by Martina Bluem, the LCRA plans to intersect the Colorado River centerline with perpendicular cross-sections the width of the 500-year floodplain. In this way, each of the cross-sections can be attributed with the river measure at the intersection point. A triangulated irregular network (TIN) is built from the cross-sections, with the values stored in the TIN being the river measures. The river measure coordinate of a house on the river bank can be determined by reading the TIN value at the house location.

For measure assignment, the streams in *co_sp83f_0523* were imported into a feature dataset within a personal geodatabase in ArcCatalog. The extents of the feature dataset were defined so that the feature dataset could hold any of the available data for the Colorado River basin or the City of Austin. The complete reference frame parameters are listed in Appendix B. During importation, the lines were converted to a type of polyline called PolylineM, which contains an x, y and m coordinate at each vertex. The "new geometric network" tool in ArcCatalog was used to construct a network from the streams and a set of points containing every stream endpoint or intersection. The network allows the user to select a point to be a sink and assign flow direction towards this sink to every reach. Figure 5.9 shows the network flow direction arrows pointing downstream.

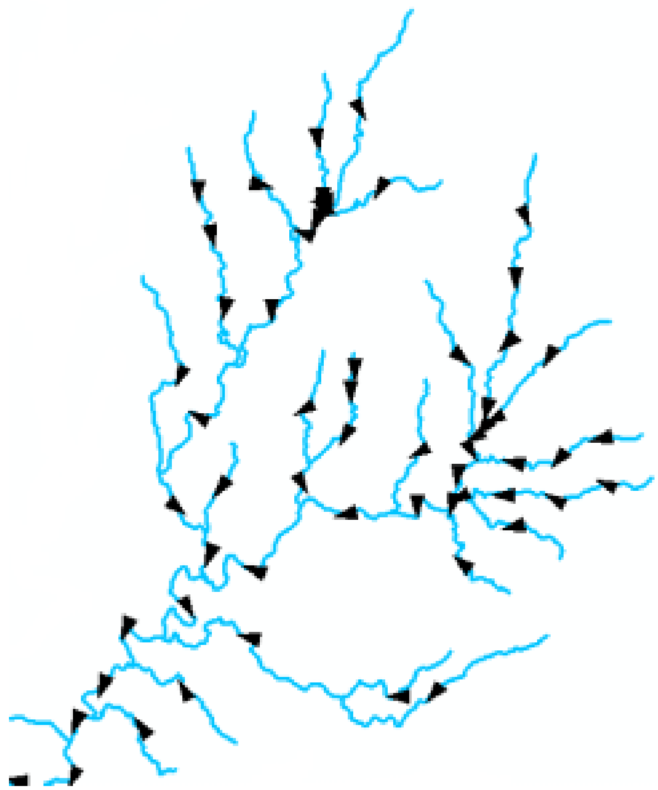
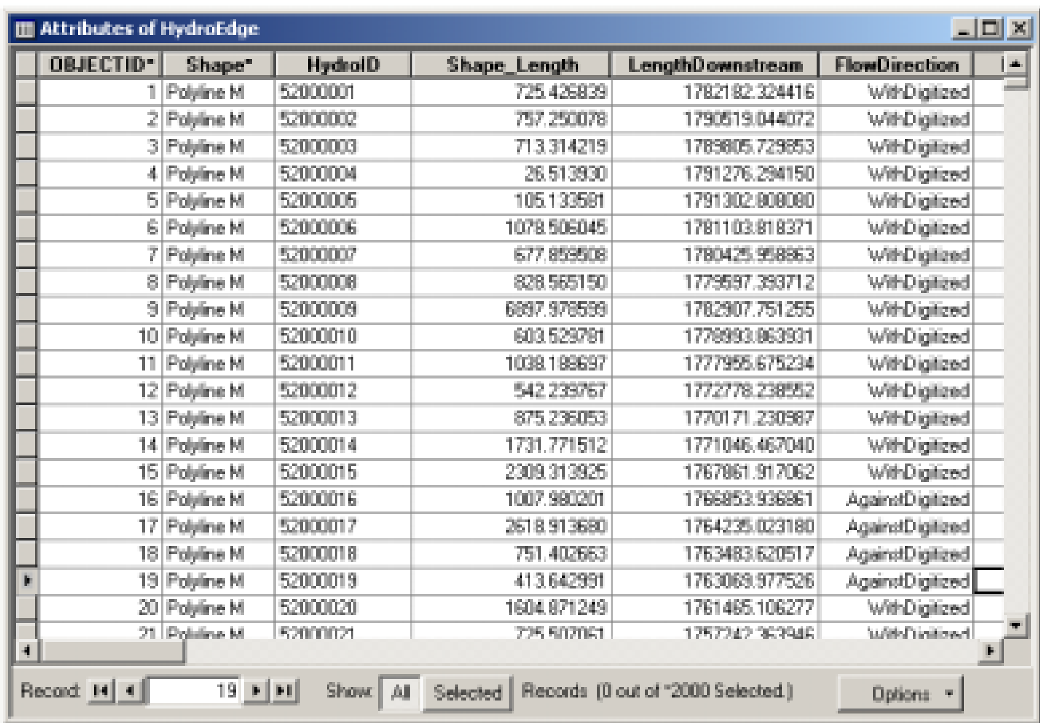


Figure 5.9. Flow direction on a network

Three attribute fields in the attribute table for the streams were populated, ShapeLength, LengthDownstream, and FlowDirection. ShapeLength is automatically populated by ArcGIS with the length of each reach in the map units, which are feet, when the shapefile is imported into the geodatabase. LengthDownstream was populated with the "Calculate Downstream Length for

Edges" tool, a part of the ArcHydroTools toolbar written by Tim Whiteaker that can be added to the project in ArcMap. For each reach, the ShapeLength field for all reaches downstream of this reach is summed and the sum in the map units of feet is placed in LengthDownstream. The FlowDirection attribute field was populated using the "Assign Flow Direction" tool within ArcHydroTools. An integer signifying either "with digitized", "against digitized", or "indeterminate" is placed in the attribute table according to whether the network flow direction is with or against the direction of digitization of the arc. Figure 5.10 shows the attribute table after the three fields needed for linear referencing are populated.



Attributes of HydroEdge

| OBJECTID* | Shape* | HydroID | Shape_Length | LengthDownstream | FlowDirection |
|---|---|---|---|---|---|
| 1 | Polyline M | 52000001 | 725.426839 | 1782182.324416 | WithDigitized |
| 2 | Polyline M | 52000002 | 757.250078 | 1790519.044072 | WithDigitized |
| 3 | Polyline M | 52000003 | 713.314219 | 1789805.729853 | WithDigitized |
| 4 | Polyline M | 52000004 | 26.513930 | 1791276.294150 | WithDigitized |
| 5 | Polyline M | 52000005 | 105.133581 | 1791302.808080 | WithDigitized |
| 6 | Polyline M | 52000006 | 1078.506045 | 1781103.818371 | WithDigitized |
| 7 | Polyline M | 52000007 | 677.859508 | 1780425.958863 | WithDigitized |
| 8 | Polyline M | 52000008 | 828.565150 | 1779597.393712 | WithDigitized |
| 9 | Polyline M | 52000009 | 6897.978599 | 1782907.751255 | WithDigitized |
| 10 | Polyline M | 52000010 | 603.529781 | 1778993.863931 | WithDigitized |
| 11 | Polyline M | 52000011 | 1038.188697 | 1777955.675234 | WithDigitized |
| 12 | Polyline M | 52000012 | 542.239767 | 1772778.238552 | WithDigitized |
| 13 | Polyline M | 52000013 | 875.236053 | 1770171.230987 | WithDigitized |
| 14 | Polyline M | 52000014 | 1731.771512 | 1771046.467040 | WithDigitized |
| 15 | Polyline M | 52000015 | 2309.313925 | 1767861.917062 | WithDigitized |
| 16 | Polyline M | 52000016 | 1007.980201 | 1766853.936861 | AgainstDigitized |
| 17 | Polyline M | 52000017 | 2618.913680 | 1764235.023180 | AgainstDigitized |
| 18 | Polyline M | 52000018 | 751.402663 | 1763483.620517 | AgainstDigitized |
| 19 | Polyline M | 52000019 | 413.642931 | 1763069.977526 | AgainstDigitized |
| 20 | Polyline M | 52000020 | 1604.871249 | 1761465.106277 | WithDigitized |
| 21 | Polyline M | 52000021 | 725.507061 | 1757242.363946 | WithDigitized |

Record 19 Show: All Selected Records (0 out of *2000 Selected.) Options

Figure 5.10. Attribute table with ShapeLength, LengthDownstream, and FlowDirection populated

M-values could then be calculated on the Shape field of the streams feature class by interpolating measures on each reach between the LengthDownstream and the (ShapeLength + LengthDownstream). A right-click on the Shape field in the attribute table presents the option to “calculate feature”. This option was selected and an Advanced calculation was done to interpolate the m-values. An If statement forced the interpolation to go in the opposite direction if the FlowDirection field indicated that the flow direction was against the digitized direction. Figure 5.11 shows the calculation window for the calculation of m-values, and Appendix C contains the list of commands used for the calculation.

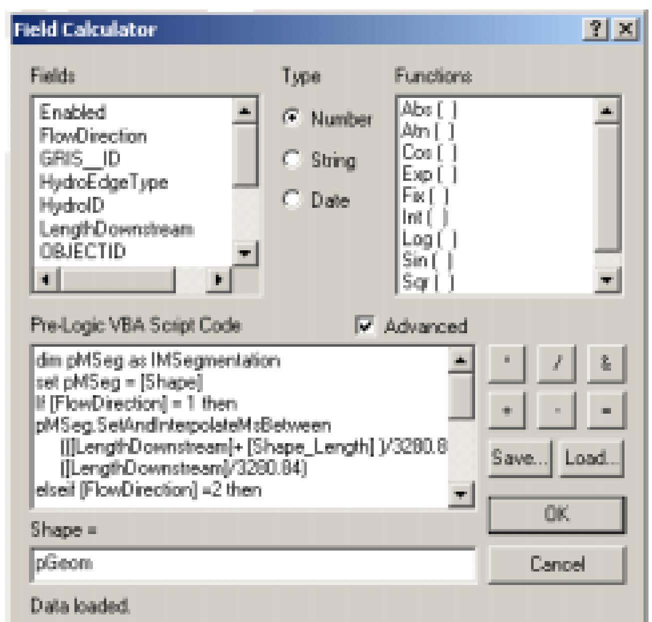



Figure 5.11. Calculation window for m-value calculations

Measures from the coast in kilometers are assigned at each vertex in the hydro edge.  From Figure 5.12 it can be learned that the outlet of Lake Travis is 518 kilometers from the Gulf, following the path of the Colorado River.

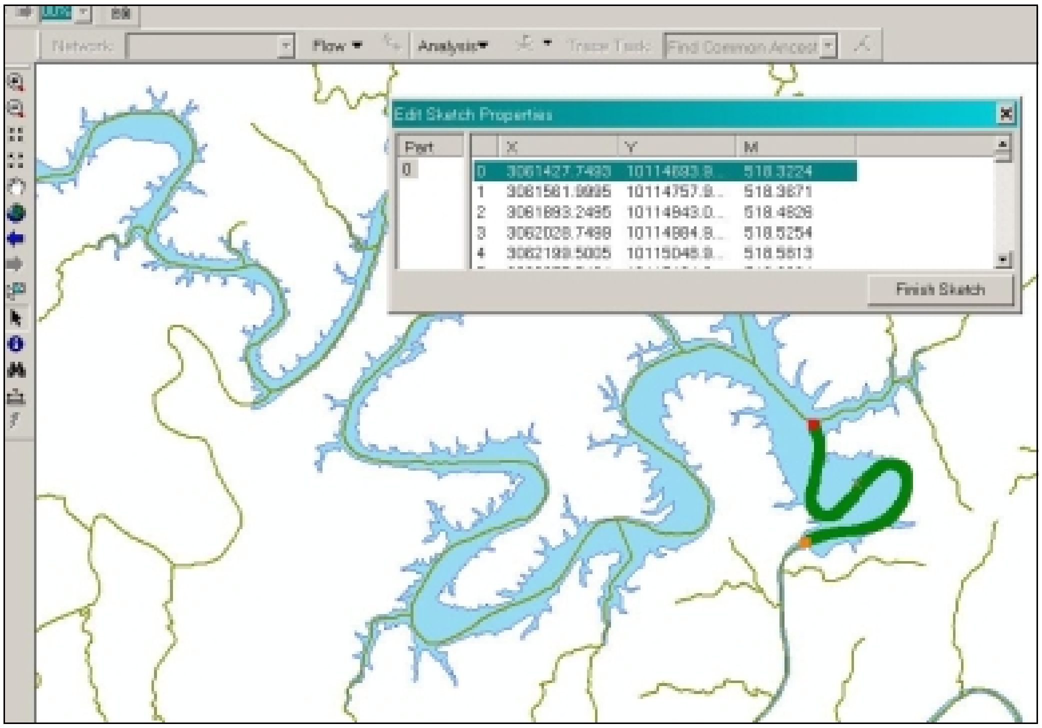



Figure 5.12.  Vertices of this reach in Lake Travis are highlighted and the Shape Properties table shows x, y and m coordinates

Figure 5.13 is a close up of Mansfield Dam at the outlet of Lake Travis, showing the individual vertices for which measures are assigned.

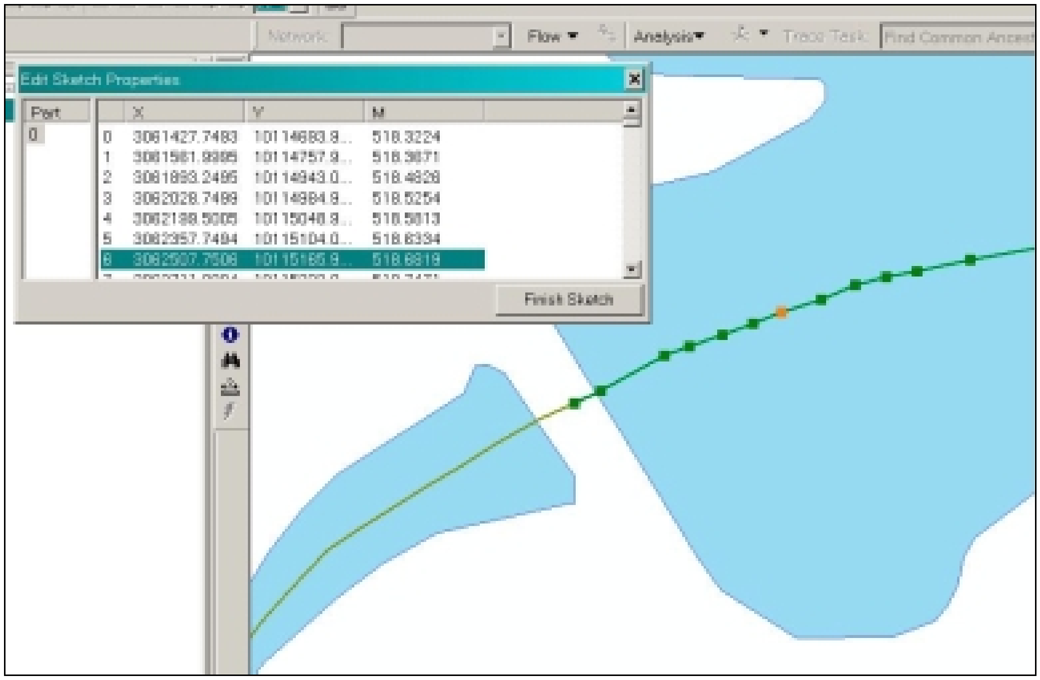



Figure 5.13. A close-up of the vertices at Mansfield Dam

## 5.2 DELINEATION OF WATERSHEDS

Elevation grids were processed to prepare grids for watershed delineation, and then watersheds were delineated from two sets of outlet points to create one set of 11,231 watersheds and catchments and one set of 232 watersheds.

### 5.2.1 Elevation Grid Preparation

In the study area, there are two controlled reservoirs being modeled, Lake Ivie at Stacy Dam and Lake Travis at Mansfield Dam. In these reservoirs water surface elevation can vary significantly while the other reservoirs have nearly constant water surface elevation. The hydrology study region thus involves two separate sections of the basin, an upper subbasin encompassing the area between

Stacy Dam and Mansfield Dam, and a lower subbasin containing the area downstream of Mansfield Dam, as pictured in Figure 5.14. The rest of the data processing was done for each of these two subbasins separately.

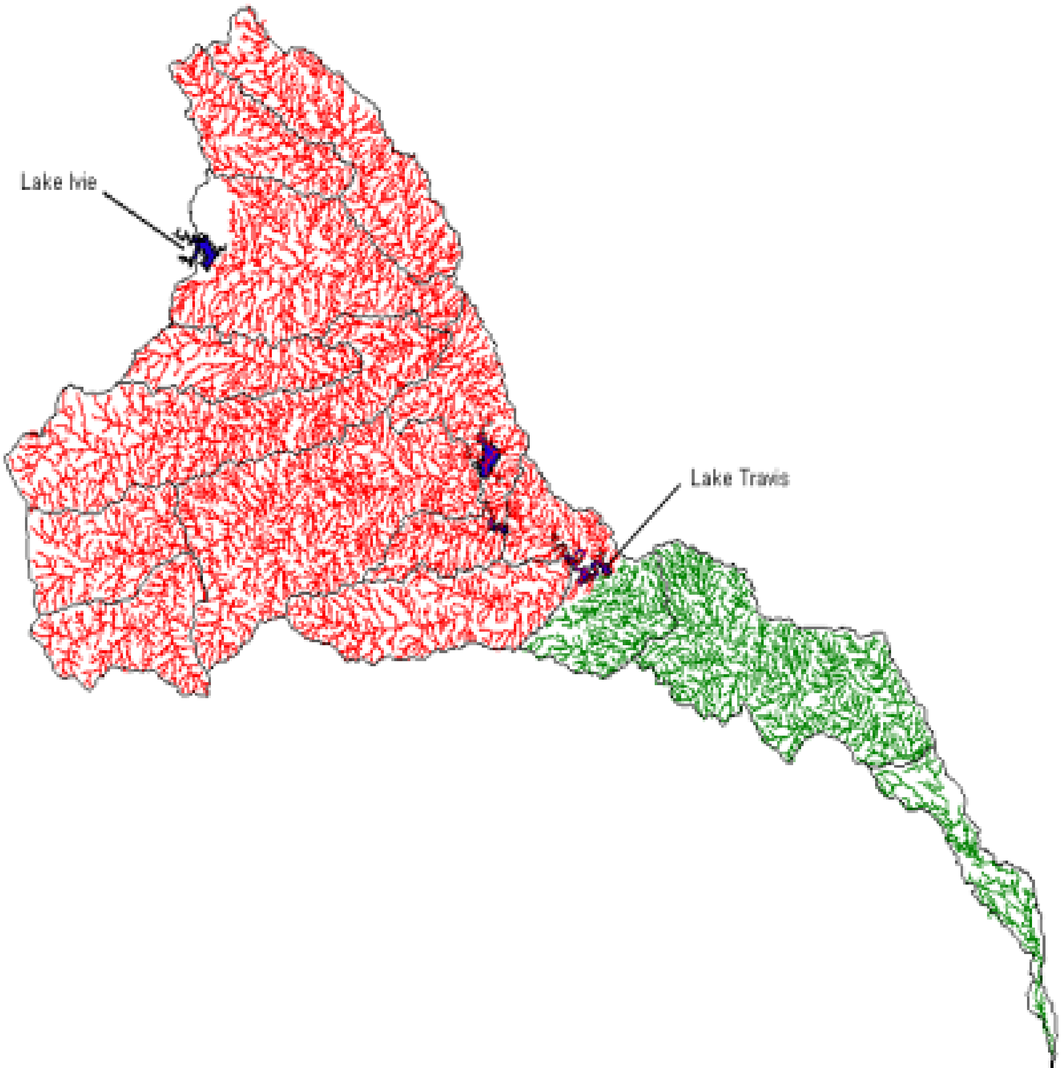



Figure 5.14. The upper and lower subbasins in the LCRA study and the 8-digit HUC units

The original DEM from the National Elevation Dataset was processed by burning in the streams, filling the sinks, and computing a flow accumulation grid and a flow direction grid. A stream network and links network were derived from these grids. Various outlet grids were created, and watersheds were delineated from the outlets and the flow direction grid.

The elevations of each of the DEM tiles were multiplied by 100 to preserve accuracy, changing the elevation units from meters to centimeters. The DEM tiles were then converted from floating point to integer grids, significantly reducing the amount of memory needed to store them. The integer grids were merged into an upper and a lower section, one downstream of Mansfield Dam and one between Mansfield Dam and Stacy Dam. Both grids were projected from their original geographic coordinates to State Plane, Texas Central Zone, 1983 datum, with map units in meters. The grid cell size was set to 30 meters. See Appendix D.1 for the text of the projection file.

During the projection, the **setwindow** command was used to ensure that the cells in the upper DEM matched exactly over the cells in the lower DEM, so that watersheds delineated from these DEMs would have common boundaries at the border between them. Figure 5.15 shows the misalignment of grid cells that is a potential cause of errors.

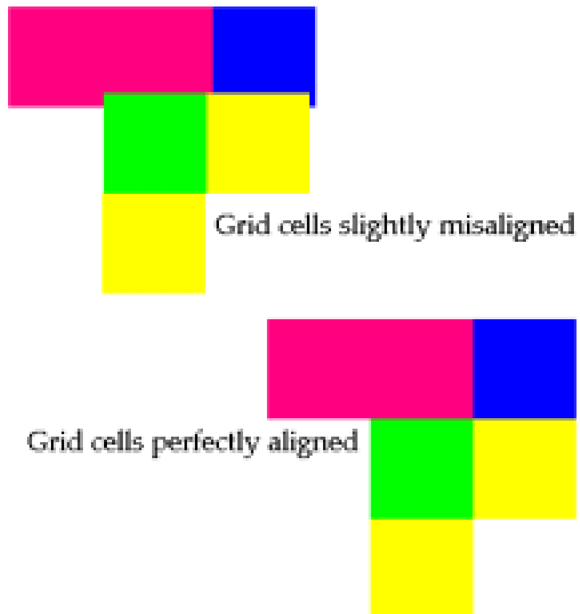



Figure 5.15. Errors occur when cells from different grids do not match exactly over each other

The **shapearc** command in ArcInfo was used to create a coverage of the stream network and of frames around the upper and lower subbasins that would be used to clip the DEM sections to make them more manageable.

*Arc:* **Shapearc <co_sp83m_0528> <co_0528>**
*Arc:* **Shapearc <upperframe> <upperframe>**
*Arc:* **Shapearc <lowerframe> <lowerframe>**

The stream network *co_sp83m_0528* is very similar to the stream network *co_sp83f_0523*, the creation of which was described in section 5.1. The only difference is that *co_sp83m_0528* is in meters instead of feet, and the main stem of the Colorado in *co_sp83m_0528* is extended downstream into the Gulf until it reaches the edge of the DEM grid. *Upperframe* is a frame drawn by hand around the upper subbasin with a buffer distance of at least 10 kilometers beyond basin boundary defined by the 8-digit HUC units.

The ArcInfo Grid program was used to do most of the remaining processing on the DEMs. The same DEM processing can also be done using CRWR-PrePro. The CRWR-PrePro user must be sure to set the analysis extent, the analysis cell size, and the mask grid to be the same as the projected DEM.

The first step after starting Grid was to set the window, cell size, and locations of new grid cells to match up exactly with the old grid cells. The following commands were used on both the upper and lower subbasins although the file names, listed here in brackets, are for the upper subbasin. *Upper_sp83m* is the projected, uncut DEM for the upper subbasin.

*Grid:* **Mapex <upperframe>**
*Grid:* **Setwindow <upperframe> <upper_sp83m>**
*Grid:* **Setcell <upper_sp83m>**

The "no data" and extraneous data cells around the outside of the frame were clipped.

*Grid:* **<co_upper> = selectpolygon(<upper_sp83m>, <upperframe>, inside)**

A grid mask of the stream locations was created from the stream network coverage as follows.

*Grid:* **<strgrd> = linegrid(<co_0528>)**
*Grid:* **<strgrd1> = <strgrd> / <strgrd>**
*Grid:* **<demstr> = <strgrd1> * <co_upper>**

The streams were "burned" into the DEM by adding 100,000 centimeters to the DEM elevations everywhere except the stream locations. *Demstr* is listed before *demplus* in the input to the "merge" command so the *demstr* values replace any *demplus* values they overlap.

*Grid:* **<demplus> = 100000 + <co_upper>**
*Grid:* **<burndem_u> = merge(<demstr>, <demplus>)**
*Grid:* **Buildvat <burndem_u>**

The sinks in the DEM were filled and flow direction and flow accumulation grids were created with the following commands.

*Grid:* **Fill <burndem_u> <cofil_u> # # <cofdr_u>**
*Grid:* **<flacc_u> = flowaccumulation(<cofdr_u>)**

A new stream network was created from the DEM with a threshold drainage area of 1 square mile, which translates to 2878 grid cells of size 30 meters by 30 meters.

*Grid:* **<streamnet> = con(<flacc_u> > 2878, 1)**

A unique value was assigned to each link in the new stream network. A link is a flow edge between two stream confluences.

*Grid:* **<links> = streamlink(<streamnet>, <cofdr_u>)**

A grid was then created with one outlet cell at the downstream most cell of each link. CRWR-PrePro was used for this process. Under the Analysis Properties menu, the analysis extent, analysis cell size and mask grid were set to be the same as the projected DEM, *co_upper*. The CRWR-PrePro "outlets from links" option was used to create an outlet grid (*oultgrd*) from the flow accumulation grids.

### 5.2.1 Catchment and Watershed Delineation

Watersheds were delineated as grids and then vectorized using CRWR-PrePro. Two sets of watershed delineations are described here. The first is a set of 11,231 small watersheds and catchments with an average area of 4.25 square kilometers that was created for future small-scale work in the basin. Watersheds and catchments in this set were delineated from every stream confluence, gage and bridge crossing.

The next delineation described is a set of 232 larger watersheds with a 205 square kilometer average size. They are delineated from points of interest, gages, and HUC intersections with streams with parameters intended for calibration by Halff Associates, Inc. for basin-wide flood studies.

#### *5.2.2.1 Watersheds and Catchments from Confluences, Bridges, and Gages*

Three files were produced during this delineation. The first is a stream network (*1sm_all_dstr_edited_f_0728*) containing 11,233 links delineated from the DEMs with a 1 square mile drainage threshold defining a stream. Stream locations are forced over their locations in the vector stream network *co_sp83f_0528*. There is also a points file (*bridges_f_0714*) that contains a point for each of the 1215 bridges that cross streams in the TXDOT roads coverage and each of the 73 existing or proposed LCRA gages as of July 9, 2000, 11 of which are lake level gages and 62 of which are stream or stream and rain gages. The points lie over the cells in the stream grid used to create the DEM-delineated stream network, *1sm_all_dstr_edited_f_0728*. Links in the DEM-delineated streams file are broken at each additional drainage point from *bridges_f_0714*.

The watershed boundary shapefile (*1sm_all_wtsp_edited_f_0728*) contains watersheds and catchments delineated from outlets at every stream confluence in the DEM-delineated stream network, *1sm_all_dstr_f_0728*, and from every bridge and LCRA gage location in the points file, *bridges_f_0714.* Since delineations are done from both stream confluences and additional points of interest, the result is a combination of catchments and watersheds, the catchments being those resulting from outlet points at confluences and the watersheds being those resulting from additional outlet points.

The drainage points file *(bridges_f_0714*) was created by combining a file with gage locations and a file with bridge locations.

The gage locations shapefile, h*ydromet_ut_sp83f_0709,* was created from a shapefile given to CRWR by Martina Bluem called *hydromet_ut_07_06_2000*, which contained the LCRA's current and proposed gage locations as of July 6, 2000. This file was then edited to remove 18 duplicate gages and gages not on streams in the basin, and locate each gage exactly over the stream for which it is measuring.

*Waterbridges,* the bridge locations shapefile, contains a point on the stream network for every place where a bridge from the TXDOT roads coverage crosses a stream in the basin. Its creation is diagramed in Figure 5.16. First, a query was done to remove every record in the TXDOT roads coverage that did not contain the word bridge in the attribute field listing the type of roadway. Some hand editing was then done to remove bridges that crossed over roads rather than streams. The bridges in the TXDOT roads coverage are represented as line drawings of the bridges, and the line drawings were converted to polygons with labelpoints. The labelpoints were given Cartesian (x and y) coordinates, and these x and y coordinates were converted back to a set of points and saved as *waterbridges.*

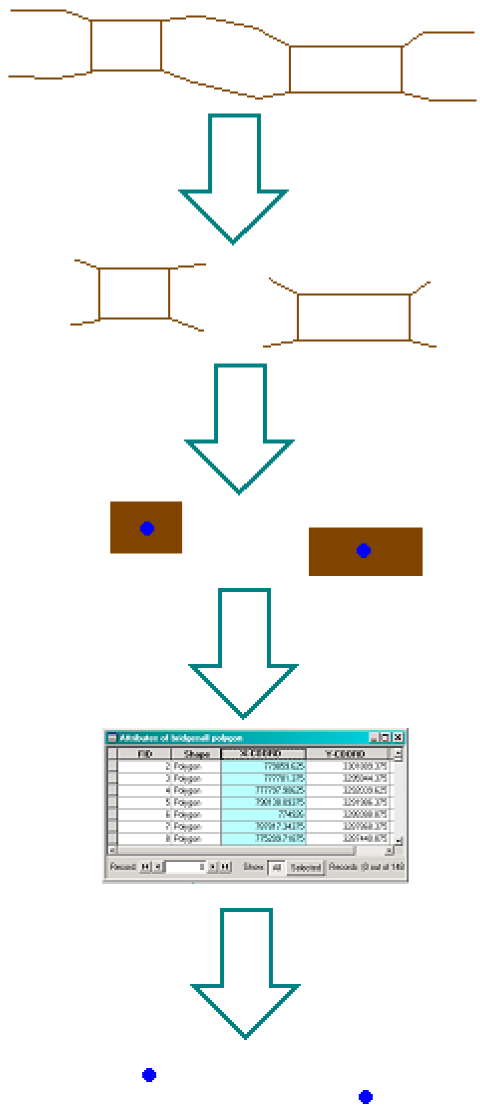


Figure 5.16. Manipulations done to obtain bridge location points from TXDOT roads coverage

A script called "snapper" written by Richard Gu and edited by Kim Davis on June 8, 1999 was used to snap each point to the nearest vertex in the DEM-delineated stream network, *1sm_all_dstr_edited_f_0728*. The new x and y coordinates and snap distances were calculated and saved as in the attribute table. The script snaps the point to the nearest vertex on the stream network. Some of the points that were not originally near a vertex were moved by hand to be closer to their original locations while still on the stream network. In the resulting points file, *waterbridges*, none of the points were moved more than 306 meters. The *waterbridges* table includes the following fields.

**Orig-x-f** and **orig-y-f** – the x and y coordinates of the original bridge in the TXDOT file (ft)
**Point-x-f** and **point-y-f** – the x and y coordinates of the point on the stream network that represents the bridge (ft)
**Orig-x-m**, **orig-y-m**, **point-x-m,** and **point-y-m** – the same coordinates as above (m)
**Snap-dis-f** – the distance that the point was snapped when it moved from its location in the TXDOT file to its location on the stream (ft)
**Snap-dis-m** – the same snap distance as above (m)
**Recno** – an arbitrary unique number for the bridge used for data organization.

The gage location file (h*ydromet_ut_sp83f_0709*) was projected to meters and merged with the bridge location file (*waterbridges*) to create the drainage points file, *bridges_0714*. The above fields were included in *bridges_0714*, as well as the Cartesian coordinates in feet for each gage location (stored in orig-y-f and orig-x-f), the gage type, and names for the gages with names.

Two new integer fields were added to the drainage points file (*bridges_0714*) called ID and Reservoir1, and both were populated with all zeroes. These field names are needed for CRWR-PrePro to operate smoothly. The “Add Outlets” option in CRWR-PrePro was used to modify the grid of outlets at stream confluences to include a new outlet cell at each bridge or gage. In the next box, the input and output names were entered as in Figure 5.17.

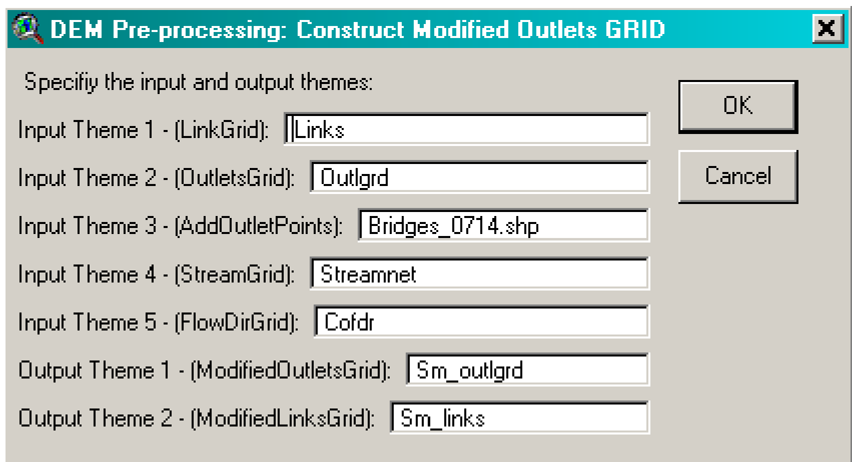



Figure 5.17. Input for creation of outlets grid for one square mile threshold watershed delineation with bridges and gages

The program was told to “Use selected outlets and outlets from links,” adding the new outlets to the outlets at each confluence already in the grid. Watersheds were delineated from the Modified Outlets Grid.

The “vectorize streams and watersheds” option in CRWR-PrePro was used to vectorize the DEM-derived streams and watersheds to make them easier to work with, and then to dissolve spurious polygons that were created during the vectorization process. The dissolve polygons process directly follows vectorization, and for the upper subbasin, produced a final message saying, “3884 dangling polygons have been merged with polygons with diagonally connected polygons".

The vectorized stream networks and sets of watersheds were manually edited to remove overlaps between the upper and lower subbasins, and watersheds that do not drain to the Colorado River. The upper and lower edited subbasin watersheds and streams were merged to one streams file (*1sm_all_dstr_edited_f_0728*) and one watersheds file (*1sm_all_wtsp_edited_f_0728*) and projected to feet.

#### *5.2.2.2 Watersheds from Points of Interest, Gages and HUC Intersections With Streams*

Three files were produced during this delineation. The first is a stream network (*poi_delstr_sp83f_0915*) containing 10,188 links delineated from the DEMs with a 1 square mile drainage threshold defining a stream with the stream locations forced over their locations in the vector stream network *co_sp83f_0528.* A points file (*poi_sp83f_0915*) contains 70 new and proposed LCRA gage locations as of July 9, 2000; 12 points of intersection between streams and 8-digit HUC boundaries; and 154 other points of interest. The numbers above do not correspond with the number of gages stated in section 5.2.2.1 or sum to the total number of watersheds in this delineation because some gages are very close to confluences where Halff Associates, Inc. added additional points of interest, causing only one watershed outlet to result from two points in the drainage points file and the record of the origin of the point to be lost. The polygon file, *poi_wtrshd_sp83f_0915*, contains watershed boundaries delineated from the points in *poi_sp83f_0915.*

A points file was created (*HUC_confluences*) that contains a point at every location in the basin where a stream intersects the boundary of an 8-digit HUC unit. *HUC_confluences* and *hydromet_ut_sp83f_0709* were merged, retaining fields with (x,y) coordinates in feet for each location, hydrologic unit codes for the HUC intersections, the gage type, and names for the gages with names. Watersheds were delineated from this combined file and circulated to Halff Associates, Inc. and the LCRA for revisions of the points of interest file.

Four further iterations of the watershed delineation were distributed from CRWR to the LCRA and Halff Associates Inc., and each time the points of interest file was revised. Revisions included adding points and moving these points to produce uniformly sized and shaped watersheds in useful locations.

The points of interest file *poi_sp83m_0915* was used for the final iteration of watershed delineation. To do the delineation, the “Add Outlets” option in CRWR-PrePro was chosen and StreamGrid was selected. In the next box, input and output names were entered as in Figure 5.18.

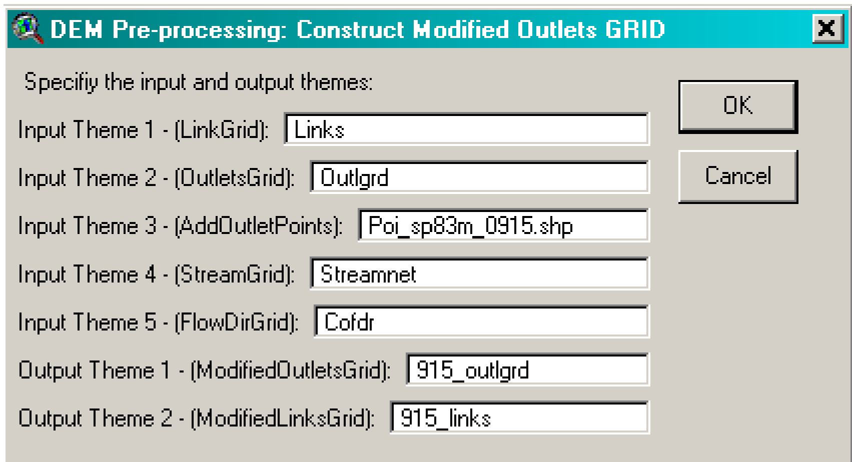



Figure 5.18. Input for creation of outlets grid for watershed delineation from points of interest

The program was told to "use only selected outlets" in order to make an outlet grid containing the points of interest but not every stream confluence. Watersheds were delineated from the modified outlets grid, creating a new watershed grid.

Streams and polygons were vectorized. The dissolve polygons process for the upper subbasin produced a final message saying, "74 dangling polygons have been merged with polygons with diagonally connected polygons".

The vectorized stream networks and sets of watersheds were edited to remove overlaps between the upper and lower Subbasins, and watersheds that did not drain to the Colorado River. The resulting edited watersheds are shown in Figure 5.19. The upper and lower edited subbasin watersheds and streams were merged to one streams file (*poi_delstr_sp83f_0915*) and one watersheds file (*poi_wtrshd_sp83f_0915*) and projected from meters to feet.

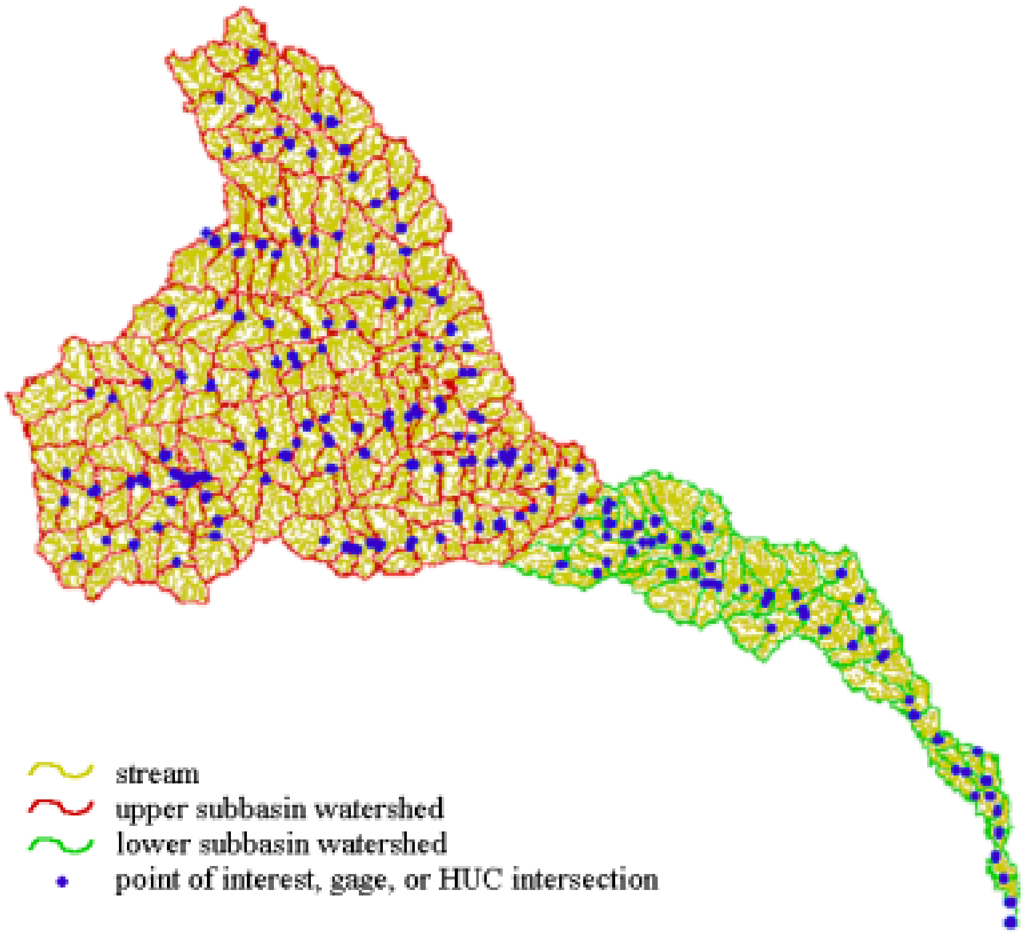



Figure 5.19. Watersheds delineated from points of interest, gages, and HUC intersections

## 5.3 COMPUTATION OF HYDROLOGIC PARAMETERS

Hydrologic parameters for each of the 232 watersheds from points of interest, gages, and HUC intersections were calculated from the watershed boundaries, stream locations, elevations, land cover and soil types. The parameters were saved as attributes in the watershed shapefile.

### 5.3.1 Land Cover Grid Preparation

The land cover data came primarily from the LCRA's 1997 land cover grid. Since 20 watersheds in the northern part of the basin and some strips near the basin edges were not covered by this data (Figure 5.20), the parts not covered were replaced by data from the USGS National Land Cover Dataset (NLCD).

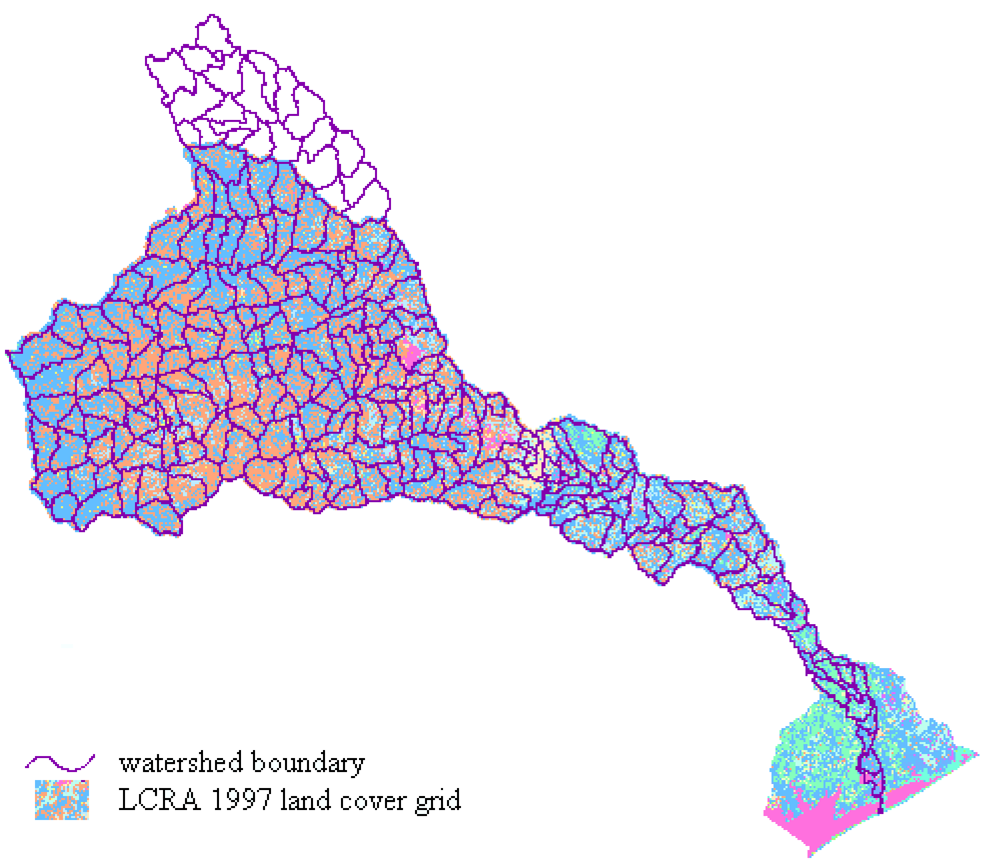



Figure 5.20. Watersheds overlain on the 1997 LCRA land cover grid

The NLCD file for Southeast Texas, *Texas_se_nlcd_092800_flat.bin*, was downloaded and the file was processed to allow it to be manipulated as a grid by ArcInfo. The file was unzipped and the extension was changed from *.bin to *.bil. An ASCII header with the same name, *Texas_se_nlcd_092800_flat.hdr*, was created with the following elements.

| | |
|---|---|
| BYTEORDERM | |
| LAYOUT | BIL |
| NROWS | 24577 |
| NCOLS | 20078 |
| NBANDS | 1 |
| NBITS | 8 |
| SKIPBYTES | 0 |
| ULXMAP | -364860 |
| ULYMAP | 1047900 |
| XDIM | 30 |
| YDIM | 30 |

The information needed to write the header file was found in the file metadata. NROWS and NCOLS are the number of rows and columns in the file. ULXMAP and ULYMAP are the y and y coordinates of the center of the upper left cell in the grid. XDIM and YDIM are the height and width of the grid cells in the map units of meters.

The BIL image was converted to an ArcInfo Grid called *texasse928*.

> *Arc:* **Imagegrid <Texas_se_nlcd_092800_flat.bil> <texasse928>**
> **# # nearest default**

The **Projectdefine** command in ArcInfo was used to define the projection of the new grid. Defining the projection creates a file within the grid listing its projection properties. The grid was in the USGS National Albers projection when it was downloaded from the website, so the projection parameters that were entered as follows are in Albers.

*Arc:* **Projectdefine grid <texasse928>**
*Project:* **Projection albers**
*Project:* **Datum NAD83**
*Project:* **Zunits no**
*Project:* **Units meters**
*Project:* **Spheroid GRS1980**
*Project:* **Xshift 0.0000000000**
*Project:* **Yshift 0.0000000000**
*Project:* **Parameters**
*1st standard parallel [ 0 0 0.000]:* **29 30 0.000**
*2nd standard parallel [ 0 0 0.000]:* **45 30 0.000**
*central meridian [ 0 0 0.000]:* **-96 0 0.000**
*latitude of projection's origin [ 0 0 0.000]:* **23 0 0.000**
*false easting (meters) [ 0.000]:* **0.00000**
*false northing (meters) [ 0.000]:* **0.00000**

A projection file for use in projecting from Albers to State plane was created, and the grid was projected to State Plane, Texas Central Zone, NAD83 datum, meters. See Appendix D.2 for the text of the projection file.

*Arc:* **Project grid <texasse928> <texasse928spm>**
**<alb_sp83m.prj> nearest 30**

One hundred was added to all the values in the NLCD grid so that values from this grid would not be confused with values from the 1997 LCRA land cover grid.

The 1997 LCRA land cover grid was extracted using the ArcInfo **import** command and projected to meters from feet using ArcInfo. See Appendix D.3 for the text of the projection file.

*Arc:* **Project grid <colo_97lc2> <colo_97lc2_m>**
**<sp83f_sp83m.prj> nearest 30 740550.4529 3331335.3616**

The two numbers, 740550.4529 and 3331335.3616, are the x_register and y_register, which ensure that the projected LCRA grid match exactly over the NLCD grid cells, making it possible to merge them in the next step. The x and y register numbers are the coordinates of the center of the upper left grid cell of the NLCD grid. They can be seen in the theme properties of the NLCD grid when viewed in ArcView. A 30 in the projection command ensures that the grid cells will be 30 meters by 30 meters, the same size as the NLCD grid cells.

The two grids were merged together. Listing the LCRA grid first in the list of grids to merge gives this one priority so that none of the LCRA data are replaced by NLCD data.

*Arc:* **<lcra97nlcd928> = merge(<colo_97lc2_m>, <texasse928spm>)**

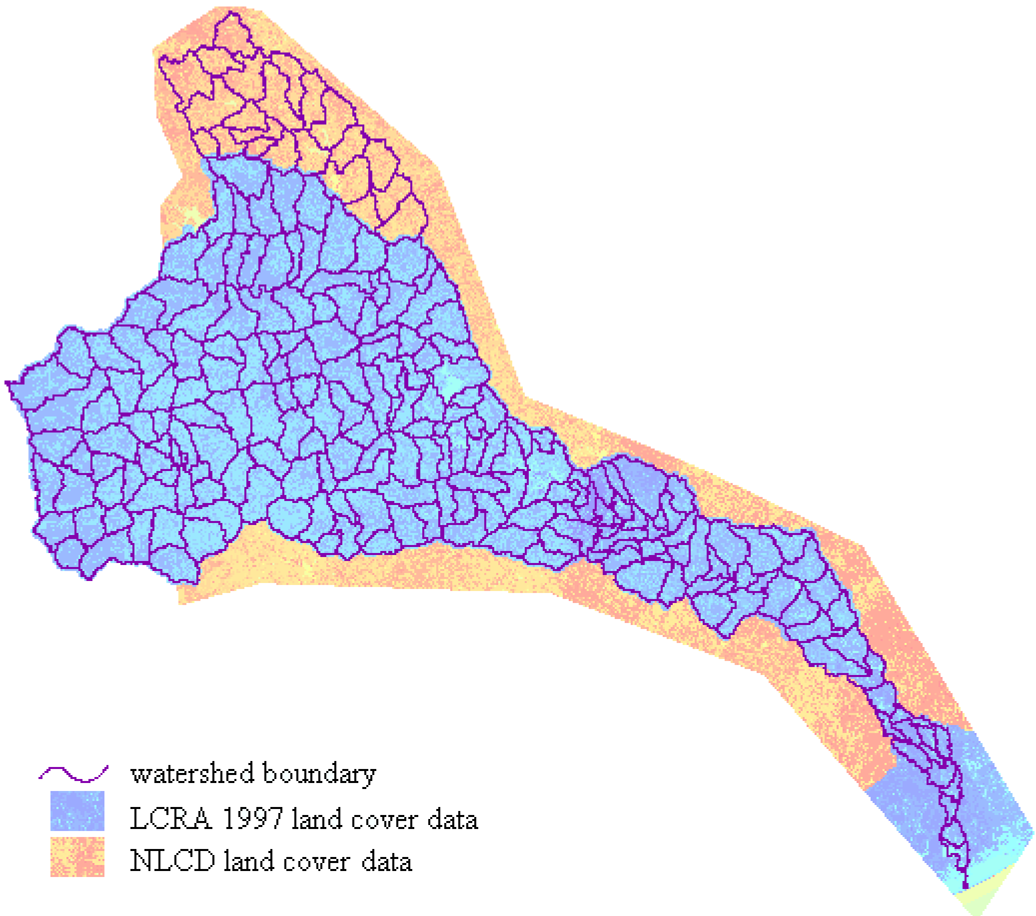



Figure 5.21. Merged grid contains LCRA land cover data and NLCD data

The resulting grid (Figure 5.21) was clipped using a polygon drawn around the basin with a small buffer, to make the grid size more manageable.

An area of about 1 square mile on the farthest western edge of the basin, illustrated in Figure 5.22, is not covered by the LCRA data or the NLCD southeast Texas data. Rather than download the NLCD grid for southwest Texas, it was assumed that all land in this area is grassland with a land use code from Table 3.1 of 20, the code of most of the surrounding land.

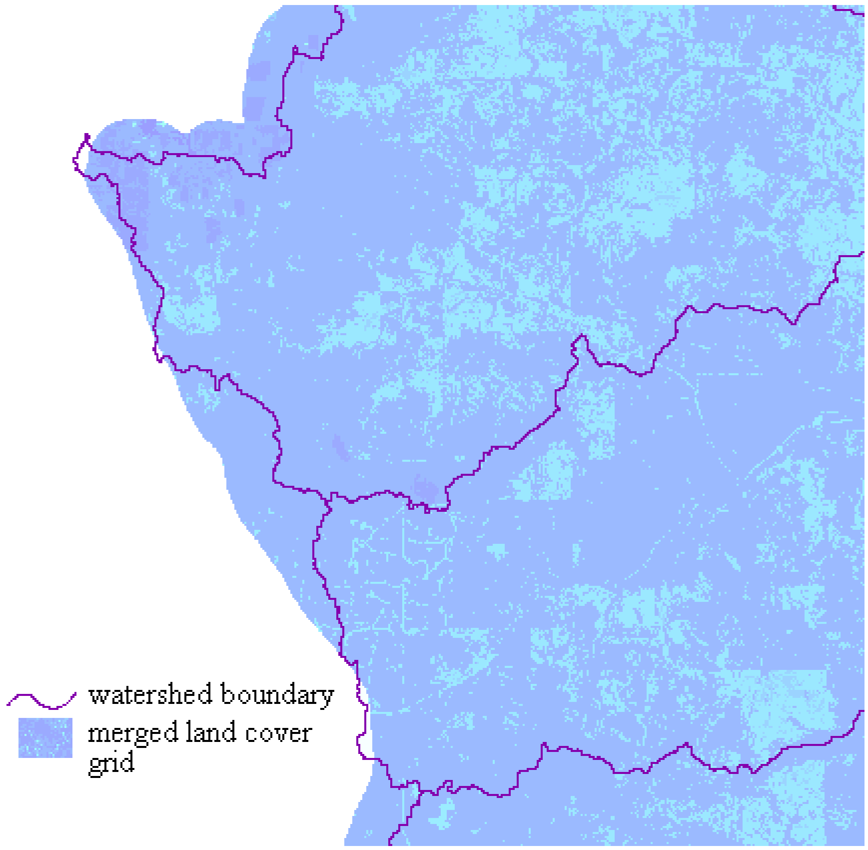



Figure 5.22. Grid needs to be extended

The areas missing data shown in Figure 5.22 were filled in by merging the land cover grid with a small grid constructed to patch the holes. A polygon ArcInfo coverage covering the area for which the grid was extended was created. This coverage was given a field with the name "value" and a value of 20. The value was assigned using ArcView. ArcInfo Grid was then started and the window and cell size were set. The **polygrid** command was used to create a grid of the coverage, and the new grid was merged with the existing land cover grid.

The following commands were used, where *gridextension* is the polygon coverage and *lcra97nlcd928* is the merged and clipped land cover grid.

*Grid:* **Setwindow <gridextension> <lcra97nlcd928>**
*Grid:* **Setcell 30**
*Grid:* **<gridext> = polygrid(<gridextension>, value)**
*Grid:* **Setwindow maxof**
*Grid:* **<lcranlcd> = merge(<lcra97nlcd928>, <gridext>)**

Cells in the LCRA study area with no data were another problem needing to be fixed before the grid could be used. The cell values 49, 47, 39, 44, and 28 in *lcranlcd*, the merged land cover grid, were unintentionally included in the LCRA land use data even though these land use codes have no meaning, so these 719 cells covering 0.25 $mi^2$ were changed to the land use code that surrounds them. The map calculator in ArcView was used to create a new grid that contains a value of 1 for each cell with one of these values and zero elsewhere. The grid was converted to a polygon using “grid to poly” on the CRWR-Utility menu in CRWR-PrePro. The polygon shapefile made it possible to find the unusable grid cells and see what type of land cover surrounded each of the areas. All cells with 49 were changed to 50; and cells with 47, 39, 44 and 28 were changed to 48. Cell values of 0 and 100 in this grid were also not defined. The 0 values originated from the no data cells in the LCRA land cover grid and the 100 values originated from no data cells in the NLCD grid. The merged land cover grid was not changed to alter the 0 and 100 values, but later on during parameter calculation, values of 0 were treated as if they were the same as the majority of their surroundings (20 - grasslands), and values of 100 were in the Gulf and treated as water, with code 70. To create a new grid (*lcranlcd2*) with the new land cover classifications, the following ArcInfo command was used.

> *Arc:* **<lcranlcd2> = con(<lcranlcd> == 49, 50, con(<lcranlcd> == 47 or <lcranlcd> == 39 or <lcranlcd> == 44 or <lcranlcd> == 28, 48, <lcranlcd>))**

Table 5.1 contains the land use categories and classification codes remaining in the merged, edited land cover grid (*lcranlcd2*). This is the grid that was used for later hydrologic parameter calculation described in sections 5.3.2.3 and 5.3.2.4.

Table 5.1. Land Use Classification Codes for *lcranlcd2*

| **Land Use Code** | **Land Use** |
|---|---|
| 0 | No Data, assume Grasslands |
| 3 | High Intensity Urban |
| 4 | Low Intensity Urban/Rural Developed |
| 5 | Golf courses and Parks |
| 10 | Cultivated Lands |
| 11 | Cultivated Lands - Flooded |
| 20 | Grasslands |
| 32 | Broad-leaved Deciduous Forest |
| 36 | Cedar |
| 37 | Pine Forest |
| 48 | Woodland/Shrubland |
| 50 | Bare Lands |
| 60 | Wetlands |
| 61 | Unconsolidated Shore |
| 64 | Saline Emergent Wetlands |
| 65 | Saline Woody Wetlands |
| 66 | Fresh Emergent Wetlands |
| 68 | Fresh Woody Wetlands |
| 70 | Water and Submerged Lands |
| 100 | No Data, assume Water |
| 111 | Open Water |

| | |
|---|---|
| 121 | Low Intensity Residential |
| 122 | High Intensity Residential |
| 123 | Commercial/Industrial/Transportation |
| 131 | Bare Rock/Sand/Clay |
| 132 | Quarries/Strip Mine/Gravel Pits |
| 133 | Transitional |
| 141 | Deciduous Forest |
| 142 | Evergreen Forest |
| 143 | Mixed Forest |
| 151 | Shrubland |
| 161 | Orchards/Vineyards/Other |
| 171 | Grasslands/Herbaceous |
| 181 | Pasture/Hay |
| 182 | Row Crops |
| 183 | Small Grains |
| 184 | Fallow |
| 185 | Urban/Recreational Grasses |
| 191 | Woody Wetlands |
| 192 | Emergent Herbaceous Wetlands |

### 5.3.2 Parameter Determination

Parameters were determined for each of the 232 watersheds delineated from points of interest, gages and HUC intersections (*poi_wtrshd_sp83f_0915*) and saved in the file's attribute table.

#### *5.3.2.1 Sub-Basin Naming Convention*

Each subbasin was given a name that is the concatenation of the 8-digit HUC unit that the watershed falls primarily within and the Gridcode that was assigned to the watershed by CRWR-PrePro. The three text fields for naming in the watershed boundary file are as follows.

**Gridcode –** a unique ID assigned to the watershed by CRWR-PrePro. Each reach in the delineated streams file contains the gridcode for its corresponding watershed.
**HUC –** the 8-digit HUC unit that the watershed primarily falls within. Some watersheds fall in more than 1 HUC unit, but there is always one for which a large majority of the area falls within.
**HUCgridcod –** the 8-digit HUC followed directly by the gridcode

#### *5.3.2.2 Sub-Basin Area*

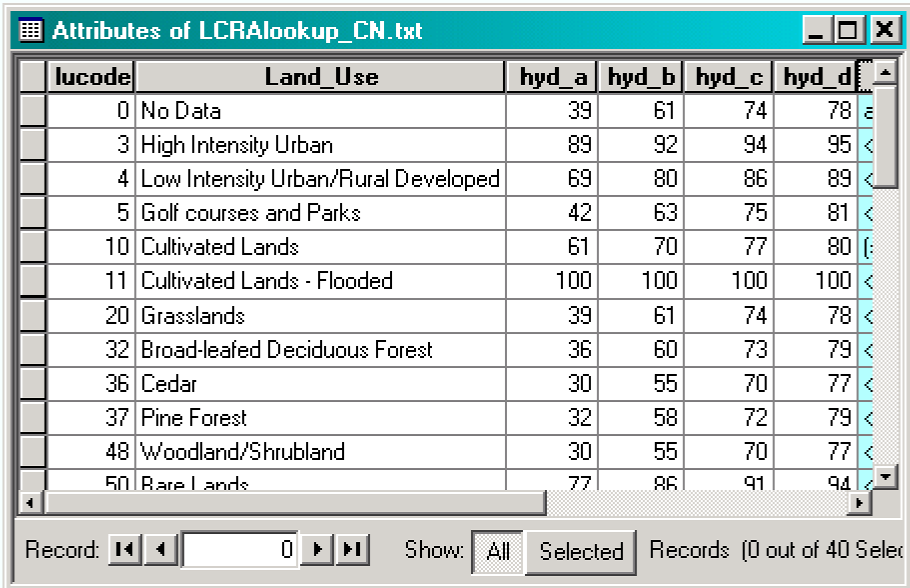
The watershed area was calculated by CRWR-PrePro when the watershed was delineated. It was calculated in square meters, converted to square miles with a conversion factor of 1 mile$^2$ = 2589988.11034 meter$^2$ and placed in a new field called Area_mi2.

#### *5.3.2.3 Initial Loss*

The Land Cover grid (*lcranlcd2*) was converted to polygons using the using "grid to poly" option on the CRWR-Utility menu in CRWR-PrePro, and saved as a shapefile (*landcov*).

STATSGO data for Texas was obtained and the *mapunit.dbf* and *comp.dbf* tables from the STATSGO data were opened in ArcView. The "Soil Group Percentages" command in CRWR-PrePro was selected. The result was a table (*muidjoin.dbf*) that contains percentages of each hydrologic soil group for each map unit.

A lookup table (*LCRAlookup_cn.txt*) was created by Halff Associates, Inc. to relate each land cover code and soil group to the appropriate curve numbers. A portion of the lookup table is shown in Figure 5.23. See Appendix A.1 for the complete lookup table text. The GRIDCODE field in the land cover polygon file contains the Land Use/Land Cover classification code, one of the codes describing land use listed in Table 5.1.




| lucode | Land_Use | hyd_a | hyd_b | hyd_c | hyd_d |
|---|---|---|---|---|---|
| 0 | No Data | 39 | 61 | 74 | 78 |
| 3 | High Intensity Urban | 89 | 92 | 94 | 95 |
| 4 | Low Intensity Urban/Rural Developed | 69 | 80 | 86 | 89 |
| 5 | Golf courses and Parks | 42 | 63 | 75 | 81 |
| 10 | Cultivated Lands | 61 | 70 | 77 | 80 |
| 11 | Cultivated Lands - Flooded | 100 | 100 | 100 | 100 |
| 20 | Grasslands | 39 | 61 | 74 | 78 |
| 32 | Broad-leafed Deciduous Forest | 36 | 60 | 73 | 79 |
| 36 | Cedar | 30 | 55 | 70 | 77 |
| 37 | Pine Forest | 32 | 58 | 72 | 79 |
| 48 | Woodland/Shrubland | 30 | 55 | 70 | 77 |
| 50 | Bare Lands | 77 | 86 | 91 | 94 |

Figure 5.23. Partial curve number lookup table

Since the land cover polygons file was 817 megabytes, too big to process all at once, it was split into three sections along land cover polygon boundary lines. The GRIDCODE fields in the polygon files were given an alias of LUCode in the attribute table.

The soils polygon theme was projected to State Plane, Texas Central zone, 1983 datum, with map units in meters. The land cover grid (*lcranlcd2*) and the curve number lookup table in Appendix A.1 were added to the project. “Curve Number Grid” was selected from the CRWR-PrePro menu. The cell size and mask grid were specified as the same as the land cover grid. This gives the resulting curve number grid cells the same size, 30 meters by 30 meters, as the land cover grid cells and ensures that the cell boundaries exactly coincide. The map extent was specified as the same as the land cover polygon file that was being processed. Values are only assigned to curve number grid cells that are over the portion of land cover data being processed.

After the three sections of curve number grid were calculated, they were merged back into one grid in ArcInfo with the following command.

*Arc:* **<CN_lcra4> = merge(<cn_l>, <cn_um>, <cn_uu>)**

The "Average grid value on polygon" option in CRWR Raster was used to create a field called CurveNum that contains the average curve number in each of the watersheds in the watershed boundaries shapefile. Another field was created called InitialLos that contains the initial loss for the watershed in inches, based on the curve number. Initial losses were calculated from the curve numbers with the following equations.

S = 1000/(Curve Number) - 10
Initial Loss = 0.20*S

#### *5.3.2.4 Uniform Loss*

Halff Associates, Inc. created a lookup table for uniform loss rates similar to the one for curve numbers. This table (*LCRAlookup_constinf.txt*) relates each land cover code and soil group to the appropriate uniform loss rate. See Appendix A.2 for the lookup table.

"Curve Number Grid" was selected from the CRWR-PrePro menu. The same process was followed as that to create the curve number grid, except that the constant infiltration rate lookup table was used.

After the three constant infiltration rate grids were calculated for the three sections of the basin, they were merged back into one grid in ArcInfo with the following command.

*Arc:* **<constinf_lcra> = merge(<constinf_l>, <constinf_um>, <constinf_uu>)**

CRWR-PrePro automatically gives a curve number of 100 to any land that is classified in the soils data as water because precipitation that falls on water is all assumed to be runoff in the model. Since infiltration rate and not curve number was being calculated during this operation, the values of 100 that CRWR-PrePro put into the constant infiltration rate grid were changed to zero, the rate of loss for a situation with 100 percent runoff.

*Arc:* **<constinf_lcra3> = con(<constinf_lcra> == 100, 0, <constinf_lcra>)**

The “Average grid value on polygon” option in CRWR Raster was used to create a field called ConstLoss that contains the average uniform loss rate in inches/hour for each of the watersheds in the watershed boundaries shapefile.

#### *5.3.2.5 Length of Main Channel Flow Path*

The rest of the watershed parameters described were calculated to support the Snyder’s Unit Hydrograph transform method.

HEC-GeoHMS was used to calculate longest flow path for each of the watersheds in both the upper and lower watershed boundary shapefiles. The “longest flow path” option can be found in the “Basin Characteristics” menu of the project view of HEC-GeoHMS as shown in Figure 4.10 of Section 4.4. Based on the flow direction grid and watershed polygons, this function identifies the longest flow path in each of the subbasins and computes its length, storing the flow paths in a shapefile. The program uses the non-burned, non-filled DEM to calculate the elevation and slope attributes during the same step. A field called WshID was created in the watershed boundary shapefiles, in meters, for the upper and lower subbasins and the gridcode values were put in this field. HEC-GeoHMS requires a field called WshID in the watershed boundary file attribute table to use the longest flow path command. The command was executed and the new longest flow path shapefiles, shown in Figure 5.24, were called *LongestFP_u* and *LongestFP_l*, and contain the following attributes, which were also stored in the watershed boundaries shapefile.

**DSElv –** elevation at the downstream end of longest flow path (m)
**Slp_Endpt –** longest flow path slope calculated using flow path endpoints (m/m)
**Slp_1085 –** average slope between points located at 10 and 85% of flow length (m/m)
**USElv –** elevation at the upstream end of longest flow path (m)
**LongestFL –** length of longest flow path in the subbasin (m)

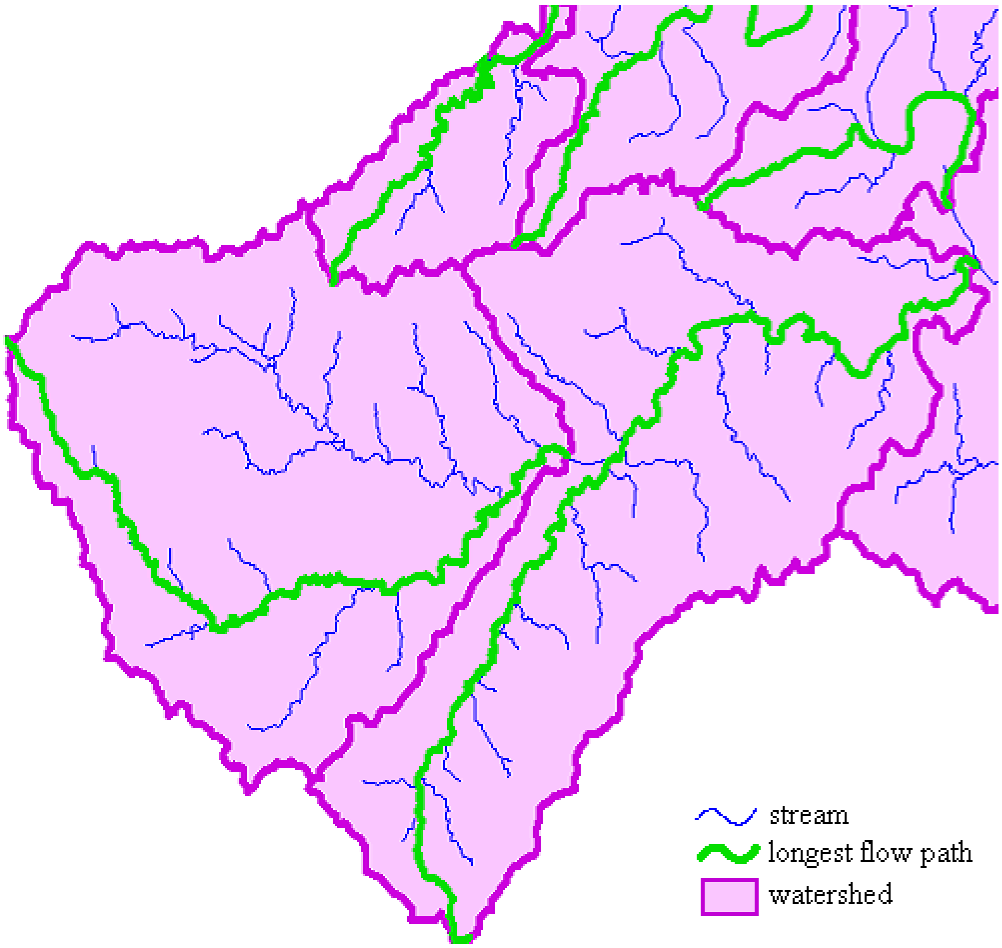



Figure 5.24. HEC-GeoHMS creates a shapefile of longest flow paths

### *5.3.2.6 Length of Main Flow Path from Discharge Point to Point Opposite Centroid*

The HEC-GeoHMS "basin centroid" option was used to find the centroid of each watershed using the "flow path" method, which places the centroid exactly 50% of the way up the length of the longest flow path, exactly on the longest flow path. The length of the centroidal flow path was then calculated with the "centroidal flow path" option in HEC-GeoHMS and is 50% of the length of the longest flow path for all watersheds.  Two new shapefiles were created for both the upper and lower subbasins.  The new files, shown in Figure 5.25, contain the centroid locations and the centroidal flow paths.   Two new attributes were added to the watershed boundary shapefile during this step.

**CentroidalFL** -- the centroidal flow length (m)
**Elevation** -- the elevation at the centroid (m)

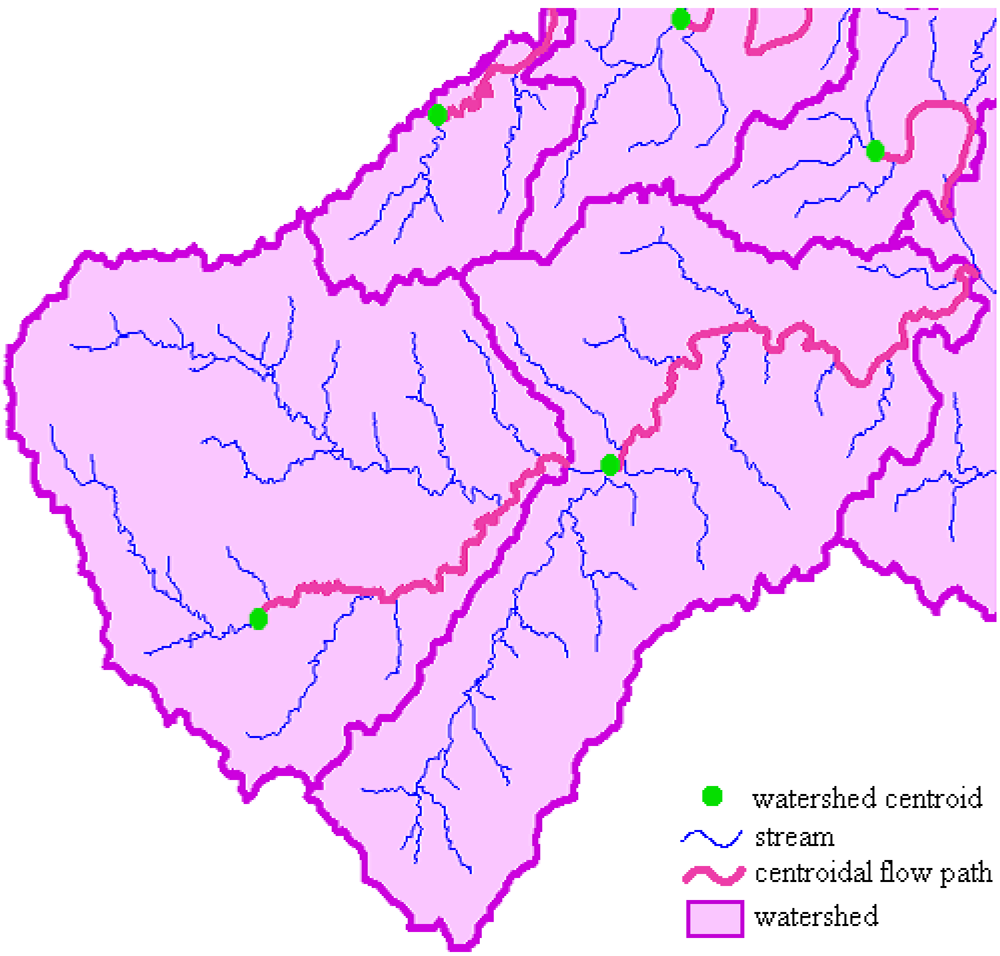



Figure 5.25.  HEC-GeoHMS creates a shapefile of centroids and centroidal flow paths

#### *5.3.2.6 Average Slope of Main Channel*

The slope of the longest flow path was calculated using HEC-GeoHMS. The calculation is done automatically when the longest flow path is computed. The Slp_1085 field added during the longest flow path calculation is the slope calculation requested by Halff Associates, Inc. and is the one to be used in the HMS schematic.

#### *5.3.2.7 Percent Urbanization*

Percent urbanized area and percent impervious cover were calculated for each watershed based on urbanization and impervious percentages for each land cover classification. The nonzero percentages among these, determined by Halff Associates, Inc., are listed in Table 5.2.

Table 5.2. Nonzero Percent Urbanization and Impervious Cover Values

| **Land Use Code** | **Land Use** | **% Urban** | **% Impervious Cover** |
|---|---|---|---|
| 3 | High Intensity Urban | 100 | 85 |
| 4 | Low Intensity Urban/Rural Developed | 100 | 50 |
| 5 | Golf courses and Parks | 100 | 5 |
| 11 | Cultivated Lands - Flooded | 0 | 100 |
| 61 | Unconsolidated Shore | 0 | 100 |
| 70 | Water and Submerged Lands | 0 | 100 |
| 100 | No Data, assume Water | 0 | 100 |
| 111 | Open Water | 0 | 100 |
| 121 | Low Intensity Residential | 100 | 50 |
| 122 | High Intensity Residential | 100 | 85 |
| 123 | Commercial/Industrial/Transportation | 100 | 85 |
| 185 | Urban/Recreational Grasses | 100 | 5 |

An urbanization grid was created containing a value of 100 for urban parks, residential and commercial areas with land use codes 3, 4, and 5, 122, 123, 121, and 185 and a zero elsewhere. The following ArcInfo command was used to create the grid (*urban*).

*Arc:* **<urban> = con(<lcranlcd2> == 3 or <lcranlcd2> == 4 or <lcranlcd2> == 5 or <lcranlcd2> == 121 or <lcranlcd2> == 122 or <lcranlcd2> == 123 or <lcranlcd2> == 185, 100,0)**

The "Average grid value on polygon" option in CRWR Raster was used to create a field called Urbaniz that contains the percent urbanization in each of the watersheds in the watershed boundaries shapefile.

#### *5.3.2.8 Percent Impervious Cover*

An impervious cover grid was created containing a percentage of impervious cover as listed in Table 5.2 for each grid cell in the land cover grid. The impervious cover grid has a value of 85% for high intensity urban, residential and commercial areas with land use codes 3, 122 and 123; 50% for low intensity urban and residential areas with codes 4 and 121; 5% for golf courses and parks with codes 5 and 185; and 100% for water with codes 70, 11, 61, and 111. A land use value of 100 means water as well as 70, 11, 61, and 111, but 100 was not included in the command below since all the values of 100 fall outside the LCRA study area. The following ArcInfo command was used to create the grid, called *ImpCov*, shown in Figure 5.26. The figure shows how water is 100 percent impervious, while dense urban areas are 50 to 85 percent impervious, and the surrounding land is 0 percent impervious.

*Arc:* **<impcov> = con((<lcranlcd2> == 3 or <lcranlcd2> == 122 or <lcranlcd2> == 123), 85, con((<lcranlcd2> == 4 or <lcranlcd2> == 121), 50, con((<lcranlcd2> == 5 or <lcranlcd2> == 185), 5, con((<lcranlcd2> == 70 or <lcranlcd2> == 11 or <lcranlcd2> == 61 or <lcranlcd2> == 111), 100,0))))**

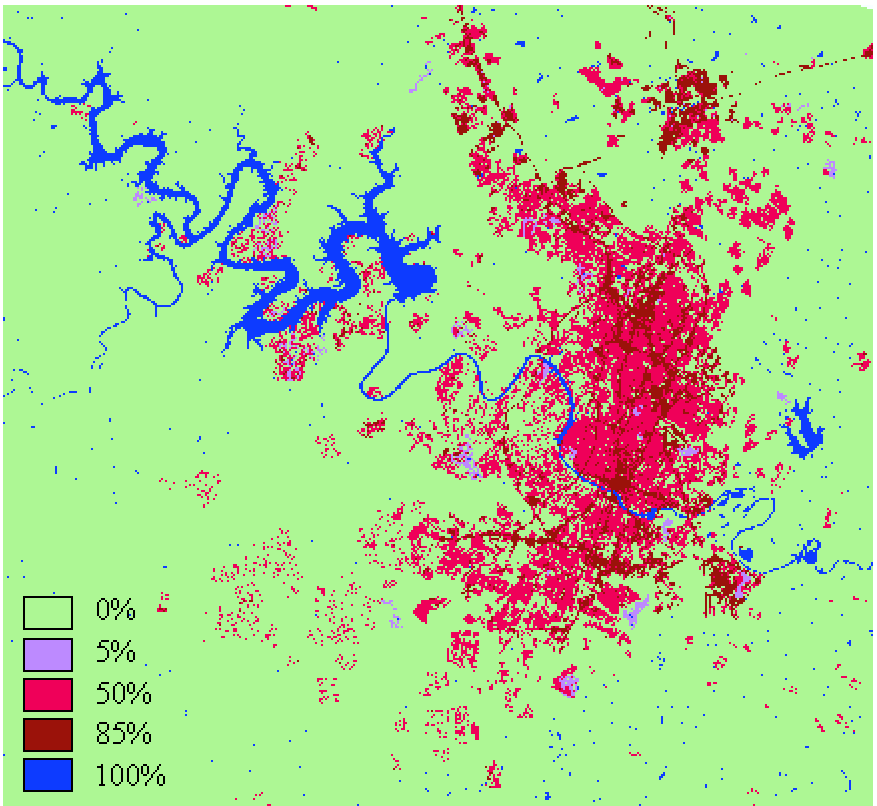



Figure 5.26. Impervious cover grid in the Austin area

The “Average grid value on polygon” option in CRWR Raster was used to create a field called Impervious that contains the percent impervious cover in each of the watersheds in the watershed boundaries shapefile.

## 5.4 PRELIMINARY HEC-HMS MODEL

The preliminary HEC-HMS model consists of ASCII text files for the upper (*co_upper_1207*) and lower (*co_lower_1207*) subbasins that contain all the basin information needed for input to HEC-HMS. The DEM-delineated stream network was redelineated to make it better for use in a basin file and then CRWR-PrePro was used to convert the GIS data to HEC-HMS input format. Map files were created to aid viewing of the files in HEC-HMS.

### 5.4.1 Revised Stream Network for Basin File

A new DEM-delineated stream network was created for use in creation of the HMS model. It is exactly the same as the stream network initially delineated during delineation of the 232 watersheds from points of interest, *poi_delstr_sp83f_0915*, except for three differences. The stream definition threshold is larger, the gridcode is different, and there is a separate file for the upper and lower subbasins. The process to delineate the streams is the same as had been done previously except that the threshold to define a stream is 100,000 cells instead of 2878, or about 35 square miles instead of one square mile. Five watersheds had to be added manually with the add streams option in CRWR-PrePro, since no stream in these watersheds was delineated automatically with the 100,000 cell threshold. The manually added streams have the following numbers in their HUCgridcod field: 120920205398, 120920205408, 120920205169, 120920205184, and 12090302236. The new threshold produces a much less detailed stream network, shown in Figure 5.27, which is better for the HEC-HMS application. To link between the new file and the old, a field containing the original gridcode called "915gridcode" is included in the new file, so that attributes can be easily referenced from one to the other.

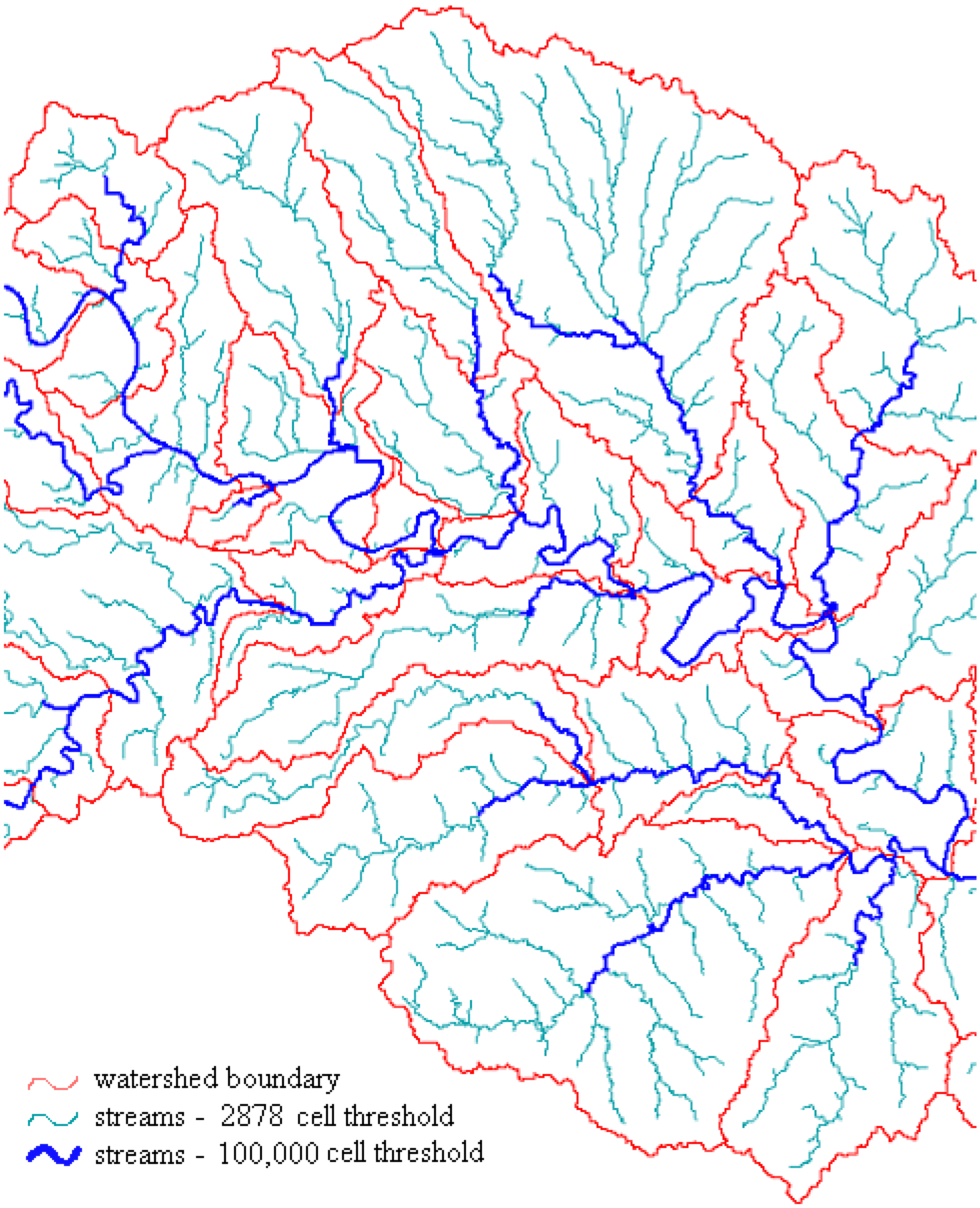
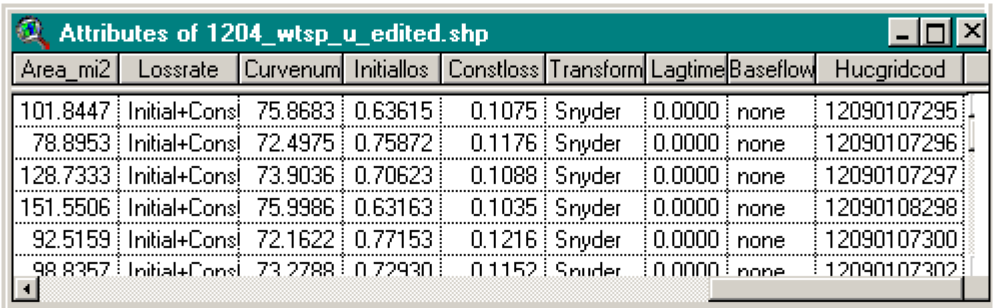



Figure 5.27. DEM-delineated streams with large and small thresholds

Watersheds were redelineated from the new streams network and the original 232 outlet points. The resulting watersheds are exactly the same as the first delineation (*poi_wtrshd_sp83f_0915*), except that the gridcode is different and there is a separate file for the upper and lower subbasins. The watershed attributes that were originally saved in the *poi_wtrshd_sp83f_0915* attribute table were transferred to the attribute tables of the new files (*poi_wtrshd_l_sp83f_1204* and *poi_wtrshd_u_sp83f_1204*).

### 5.4.2 Basin and Map File Creation using CRWR-PrePro

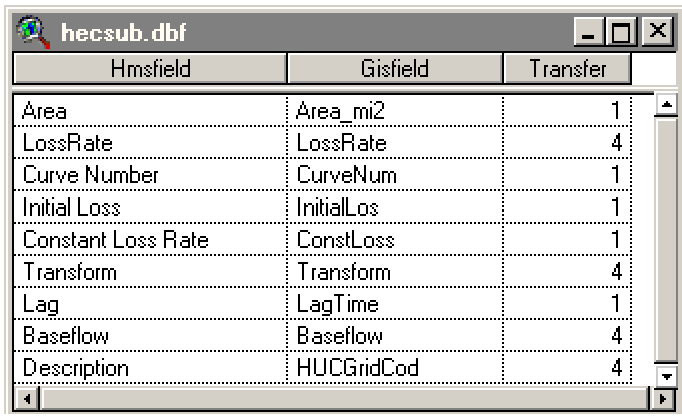
Attribute transfer tables for CRWR-PrePro were used to transfer the attributes of watershed description, area, and initial and constant loss to the HMS schematic from the watershed attribute table. Seven attribute transfer tables were used, but they were all left blank except for *hecsub.dbf*, the table used for subbasin attribute transfer. *Hecsub.dbf* was modified so the names in the "GISfield" field matched those in the GIS watershed attribute tables for the watersheds in the upper and lower subbasins delineated with the 100,000 cell drainage threshold. New fields called Lossrate, Transform, Lagtime, and Baseflow needed to be added to the attribute tables of the watershed shapefiles in order for the transfer tables to work properly. The fields were populated with default values. An attribute table with the new fields, their values, and the modified attribute transfer table, *hecsub.dbf*, are shown in Figures 5.28 and 5.29.



Attributes of 1204_wtsp_u_edited.shp

| Area_mi2 | Lossrate | Curvenum | Initiallos | Constloss | Transform | Lagtime | Baseflow | Hucgridcod |
|---|---|---|---|---|---|---|---|---|
| 101.8447 | Initial+Consl | 75.8683 | 0.63615 | 0.1075 | Snyder | 0.0000 | none | 12090107295 |
| 78.8953 | Initial+Consl | 72.4975 | 0.75872 | 0.1176 | Snyder | 0.0000 | none | 12090107296 |
| 128.7333 | Initial+Consl | 73.9036 | 0.70623 | 0.1088 | Snyder | 0.0000 | none | 12090107297 |
| 151.5506 | Initial+Consl | 75.9986 | 0.63163 | 0.1035 | Snyder | 0.0000 | none | 12090108298 |
| 92.5159 | Initial+Consl | 72.1622 | 0.77153 | 0.1216 | Snyder | 0.0000 | none | 12090107300 |
| 98.8357 | Initial+Consl | 73.2788 | 0.72930 | 0.1152 | Snyder | 0.0000 | none | 12090107302 |

Figure 5.28. New fields added to watershed attribute table for attribute transfer



hecsub.dbf

| Hmsfield | Gisfield | Transfer |
|---|---|---|
| Area | Area_mi2 | 1 |
| LossRate | LossRate | 4 |
| Curve Number | CurveNum | 1 |
| Initial Loss | InitialLos | 1 |
| Constant Loss Rate | ConstLoss | 1 |
| Transform | Transform | 4 |
| Lag | LagTime | 1 |
| Baseflow | Baseflow | 4 |
| Description | HUCGridCod | 4 |

Figure 5.29. Attribute transfer table with fields matching those in watershed attribute table

To create the HMS Schematic, “HMS Schematic” was selected in CRWR-PrePro with the new, less-detailed streams and watersheds files as input. Figure 5.30 shows the input/output window for the lower subbasin.

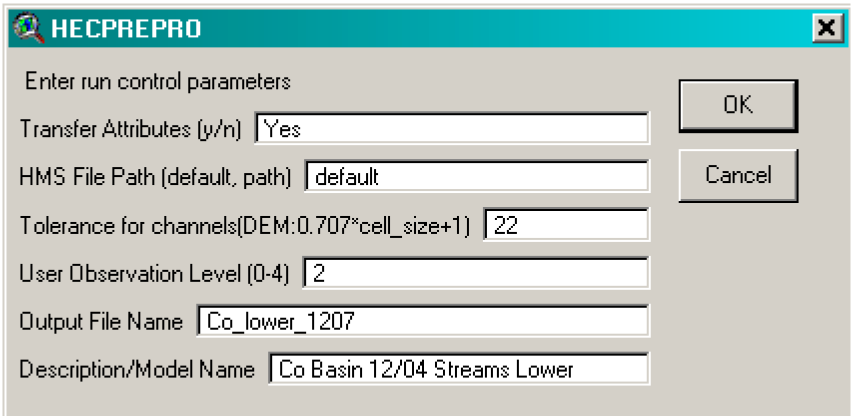



Figure 5.30. Input for HEC-HMS schematic creation

This process creates four GIS files called *hydrol*, *hydrop*, *syml* and *symp*; and the basin text file, *co_lower_1207*. Three of the four GIS files are pictured in Figure 5.31. *Hydrol* is a line theme of the river network very similar to the original network and *hydrop* contains a point at each source, sink, junction, and watershed outlet associated with *hydrol*. *Syml* is a simplified schematic of lines representing the river network and the points in *symp* represent each source, sink, junction, and watershed on the simplified network.

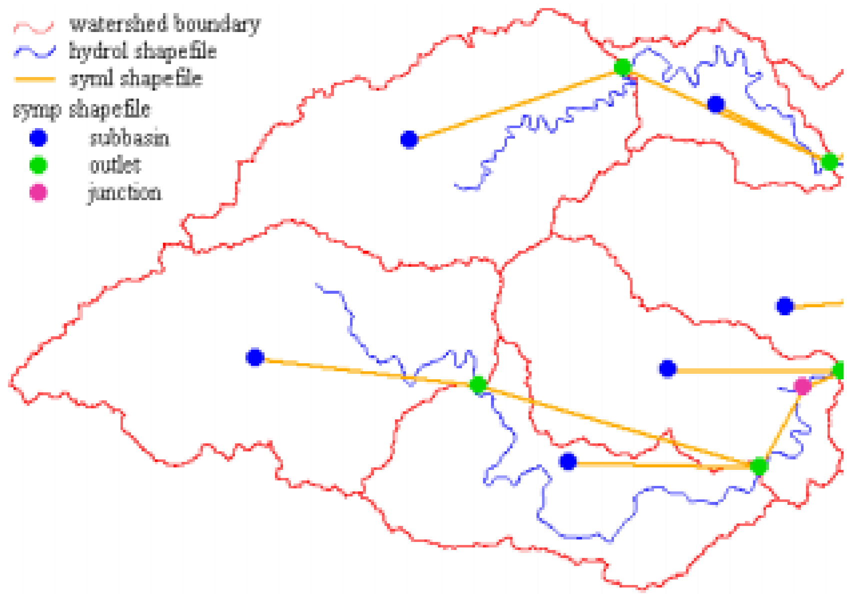



Figure 5.31. GIS schematic files *hydrol*, *syml*, and *symp*

The watershed parameters calculated in section 5.3.2 are in English units so in each of the basin text files the word “Metric” was changed to “English” so that HEC-HMS would read the parameters in English units. Figure 5.32 shows the first few lines of the basin text file, with the units changed to English.

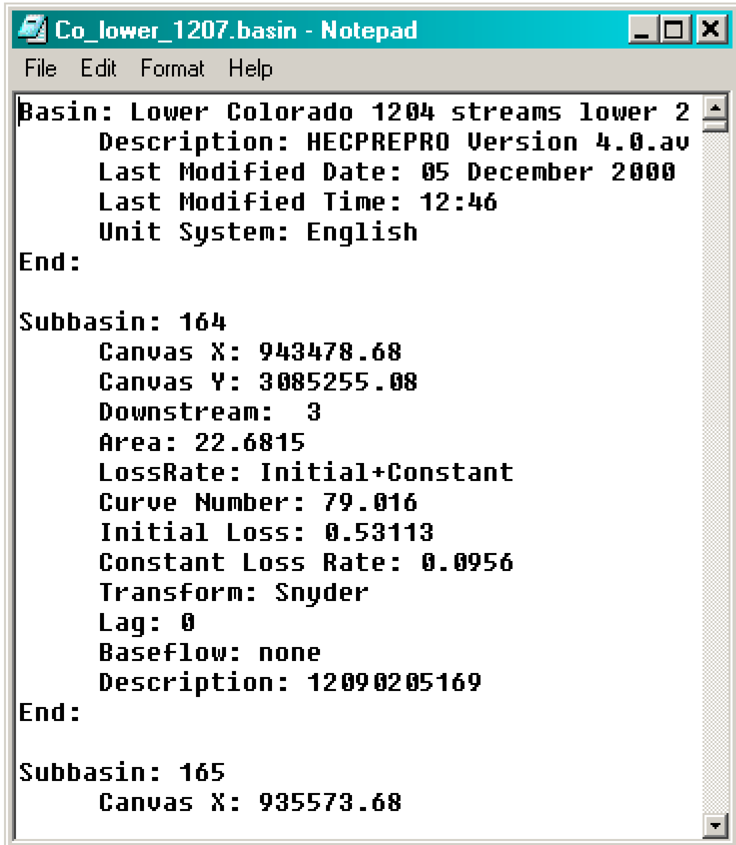



Figure 5.32. The unit system in the text HEC-HMS basin file is “English”

In the basin file for the upper subbasin, *co_upper_1207*, the watershed furthest upstream was not recognized when the basin file was created. This watershed was added and populated with attributes manually. The window in HEC-HMS where the attribute values were entered is shown in Figure 5.33, with the attributes for the watershed that was initially excluded. It’s “name”, the random number normally given to the watershed by CRWR-PrePro, is 1000, a number easy to recognize.

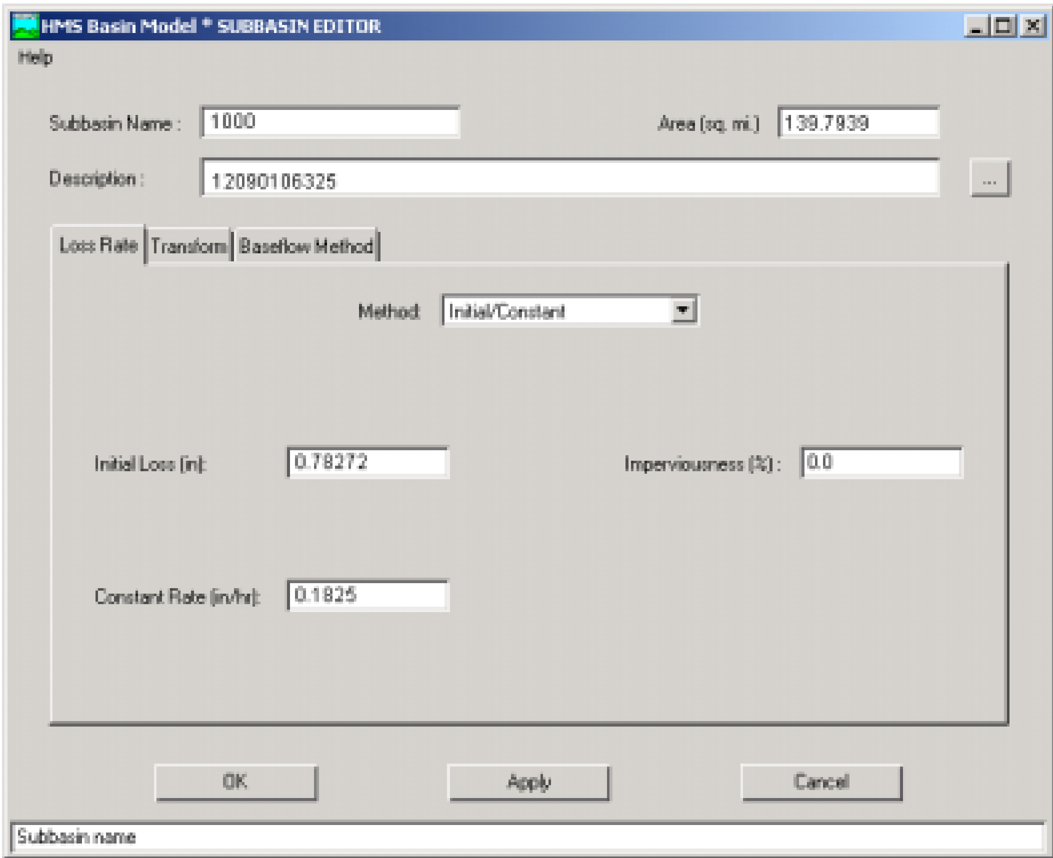



Figure 5.33. Attribute table in HEC-HMS for manually added watershed

The HEC-HMS map file was created from the GIS watershed boundaries and streams with the ArcView script “hmsmap”. The basin files, as they appear in HEC-HMS, are displayed in Figures 5.34 and 5.35. The map files can be seen in these figures as gray watershed outlines.

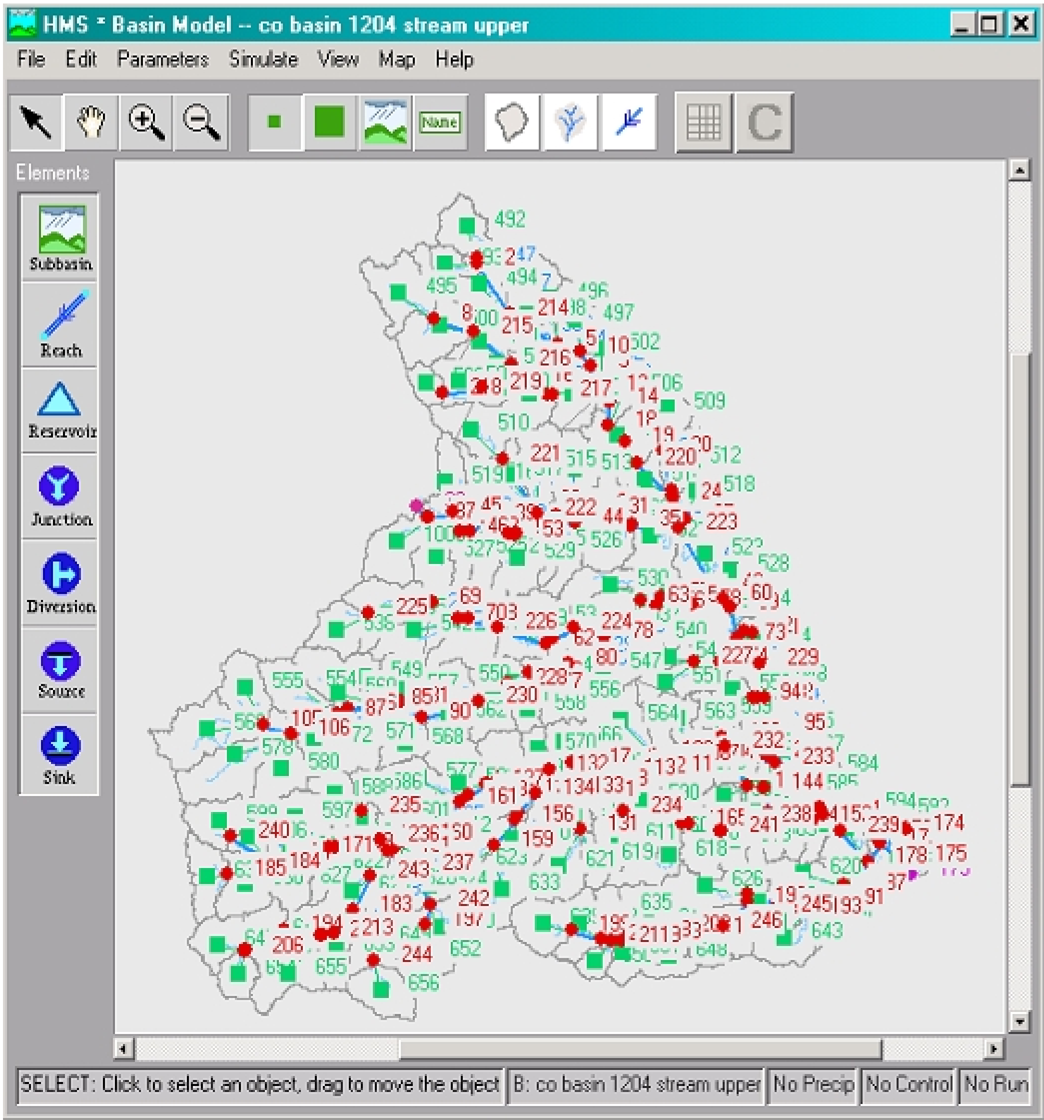



Figure 5.34. HEC-HMS basin file for subbasin upstream of Mansfield Dam

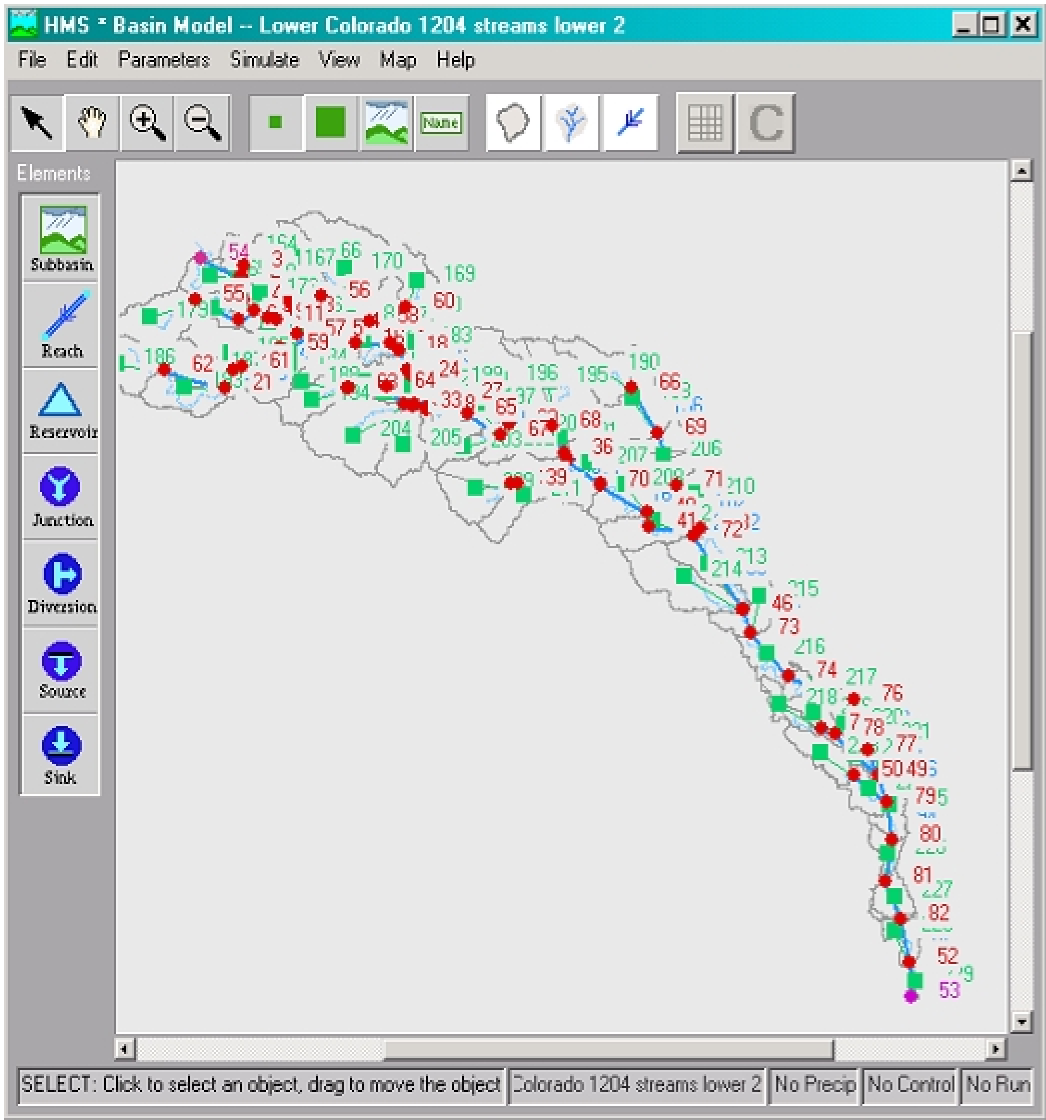



Figure 5.35. HEC-HMS basin file for subbasin downstream of Mansfield Dam

# CHAPTER 6: RESULTS AND DISCUSSION

This project resulted in a new digital network of streams in the Colorado River basin with measure values assigned along every stream, watersheds with hydrologic attributes, and an HEC-HMS model of the basin that is ready for calibration. A less tangible result is the knowledge gained during the process that will help to streamline the process for others in the future. Appendix E contains a listing of the contents of 4 CDs that are included with this thesis. The CDs were given to the LCRA and Halff Associates, Inc. at the conclusion of this project, and contain the results of the work as well as supporting files.

## 6.1 NETWORK OF STREAMS

The stream network created for the study went through an extensive editing process that makes it superior to the basin-wide networks that have been used by the LCRA in the past. The two previously most commonly used networks are the 1:100,000 scale EPA River Reach File 3 (RF3) and the TxDOT county coverages, which contain streams digitized from 1:24,000 scale USGS DRGs. The TxDOT county coverages are at a small scale, but the streams are not ready for use in hydrologic modeling. A substantial manual editing effort would be required to build the streams into a single-line network without gaps or loops. Because of integration into the 1:100,000 scale NHD network of the 1:1200 to 1:4800 scale line data from aerial photogrammetry, and newly digitized reaches based on 1:12,000 scale DOQQs and 1:24,000 scale DRGs, the new network provides a data source for the whole basin with accuracy matching that of the best data available for areas of high importance.

It was necessary to make the network seamless and single-line for the automated watershed delineation it was used for. An additional benefit to having a single-line network is the practicability of network applications such as the linear referencing done in ArcGIS 8.1.

## 6.2 A LINEAR REFERENCING SYSTEM

The new stream network contains a measure value at every vertex, totaling 515,575 measure values. The measures will be used in support of the U.S. Army Corps of Engineers FDA model, as a way to locate structures along a reach that may flood so that potential flood damage costs can be quantified.

Hargrove *et al.* (1995) warned that using the ArcInfo **densifyarc** command to add vertices to an arc would increase its total length in the arc attribute table. Since the centerline of the Colorado was densified during the NHD reach code transfer process the total length of the Colorado centerline with reach codes was compared to the length of the original centerline (*coloriv_cl).* The lengths were compared by changing each shapefile to an ArcInfo coverage and building each one. The ArcInfo Tables program allows the user to calculate statistics based on a table. The lengths of all the records in the arc attribute table of each coverage were summed. The length of the centerline to which nodes were added in order to add reach codes was 1.02 kilometers longer than the original centerline, *coloriv_cl.* The ratio of the length of *coloriv_cl* centerline to the centerline with reach codes is 0.9990.

There are two factors that could have been the primary cause for this difference. The additional nodes may have increased the length as Hargrove *et al.* (1995) suggest, or the small distortions in the line with reach codes caused by converting it to a shapefile and then back to a coverage could have increased the length. To determine which cause was more probable, the coverage created from *coloriv_cl* was converted to a shapefile then back to a coverage and rebuilt. The appearance and length of this new coverage was exactly the same as the first *coloriv_cl* coverage. This suggests that the probable cause for the difference in length between the centerlines with and without reach codes is the additional nodes in the file with the reach codes. To confirm this supposition, the coverage created from *coloriv_cl* was densified one more time by adding nodes every 10 feet. The length and appearance of the newly densified coverage more closely matched the coverage with the reach codes attributed than the coverage (*coloriv_cl)* from which it was created. This exercise provided good evidence that the small distortions in shape and length of the centerline with reach codes was not primarily due to conversion from a shapefile to a coverage and back to a shapefile, but to the addition of nodes to the coverage.

It is important to be aware of scale when working with linear referencing. When measures are in absolute units, the same point along a river can have multiple measure values depending on the scale of the data, as illustrated in Figure 6.1.

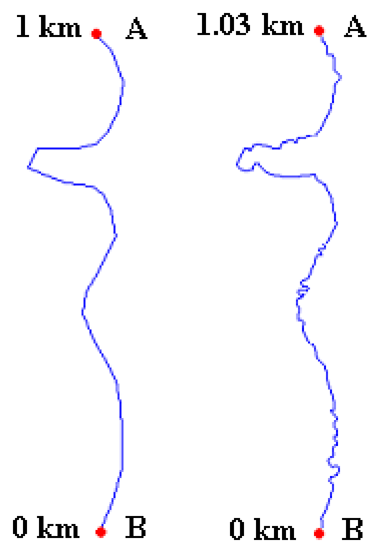



Figure 6.1. Dependence of line measure on scale

One way to avoid this problem is to use relative measurement units. With relative units, each measure is a percentage of total distance along a reach. In this way, a point has approximately the same relative measure no matter what scale the reach is represented at. This method was not used for the LCRA study because of the meaninglessness of where each reach starts and ends. Because the network is a compilation of multiple data sources, the endpoints of a reach are as arbitrary as the extent of the view during digitization.

The variety of source data from which the river network is derived means that caution should be exercised when using the measure values. Users of the network must remember the potential difference in measure values of two points approximately equal distances from the outlet if one point is on a reach from one source and the other is on a reach from another source.

To estimate the possible differences in scale, the length of the Colorado centerline digitized from the 1:12,000 scale DOQQ, *coloriv_cl*, was compared to the length of this centerline in the 1:100,000 scale NHD. There is about a 28.3 kilometer difference between the two lengths for the stretch or river between Stacy Dam and the Gulf. The ratio of the length of the *coloriv_cl* centerline to the length of the NHD centerline is 1.029. This ratio represents the amount of distortion that can be expected in measure lengths between reaches within the network from different data sources.

## 6.3 WATERSHED BOUNDARY COMPARISON

The set of 232 watersheds that were delineated were compared to the watersheds that the LCRA used prior to this study. Previously, the LCRA used a set of 29 watersheds in the Colorado River Basin based on the 1:500,000 scale USGS HUC maps with manual improvements. Twenty-six of these watersheds are in the study area for this project. Of these 26 watersheds, 22 have outlet points that correspond to outlet points in the new DEM-delineated watersheds. These 22 original watersheds were compared to the new DEM-delineated watersheds. To facilitate the comparison, the 232 DEM-delineated watersheds were merged together into 22 groups corresponding to the 22 original watersheds. The original watersheds are in blue in Figure 6.2, while the unmerged DEM-delineated watersheds are in red.

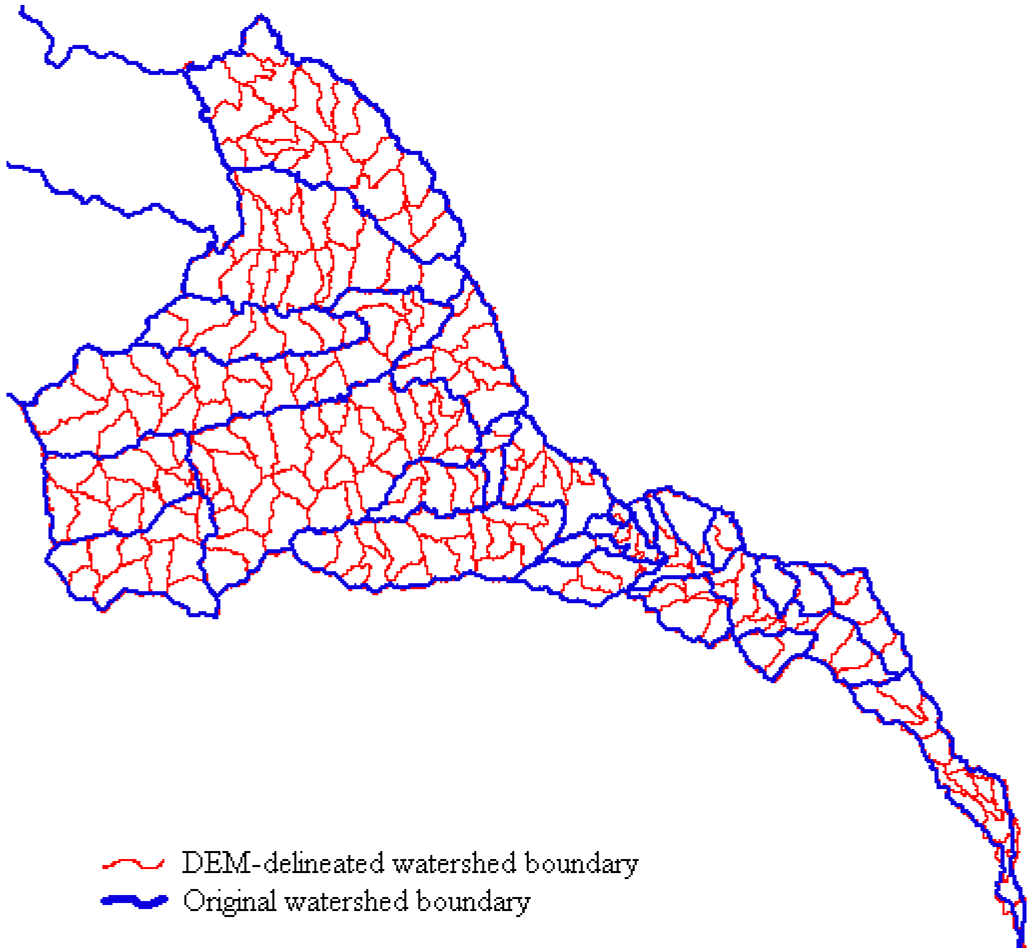



Figure 6.2. DEM-delineated watersheds (red) and original watersheds (blue)

After merging the DEM-delineated watersheds according to common outlets with the original watersheds, the DEM-delineated boundaries closely resembled the original boundaries.

A comparison of the 2 sets of watersheds overlain on the USGS DRGs shows that the DEM-delineated watersheds generally match the contour lines on the DRGs better than the original watersheds. Figures 6.3, and 6.4 show such instances.

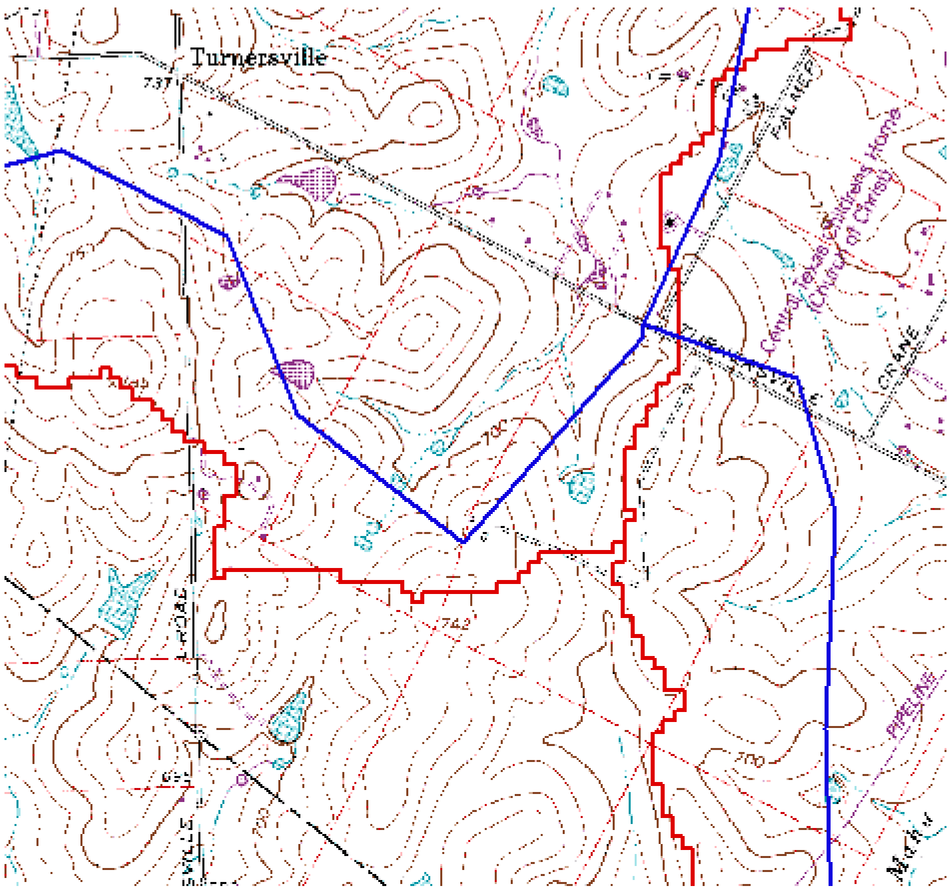



Figure 6.3. DEM-delineated boundary (red) and original boundary (blue) at basin's edge in southern Travis County

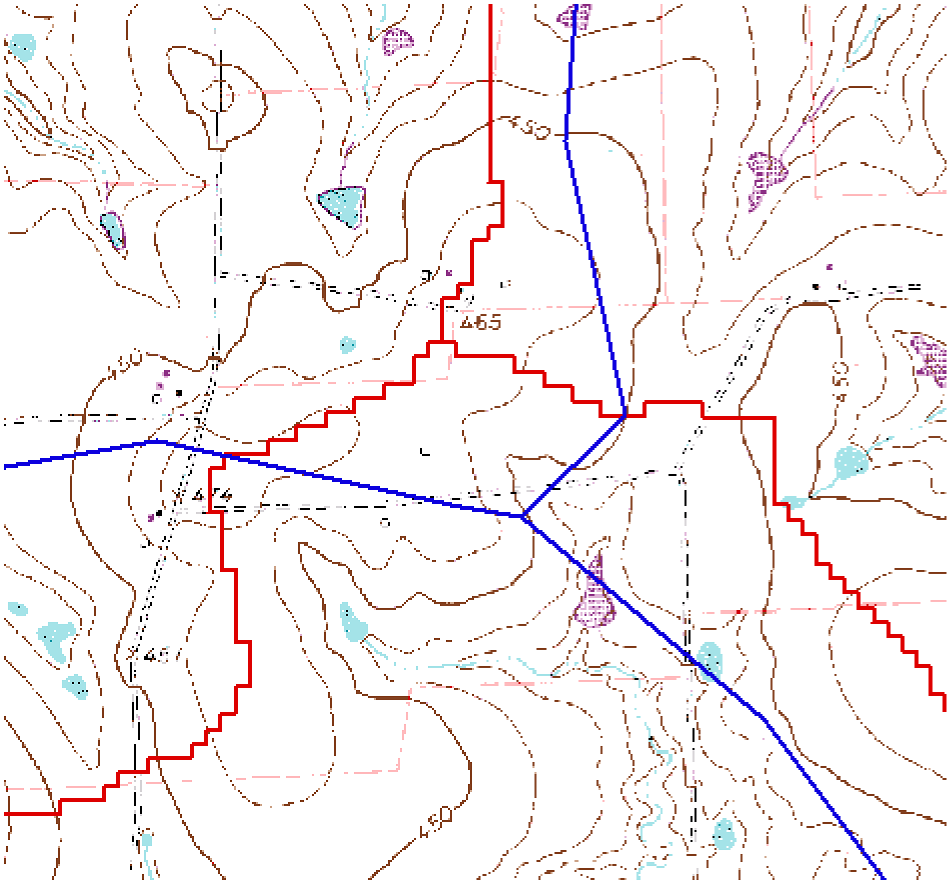


Figure 6.4. DEM-delineated boundary (red) and original boundary (blue) at basin's edge in central Fayette County

Delineation quality at lake boundaries is variable in the DEM-delineated watersheds. Since the delineation process does not explicitly account for lake shores, in certain cases the original delineations are much better, even given their larger scale. Figure 6.5, and 6.6 show two cases where the DEM-delineation method did not work well at lake outlets.

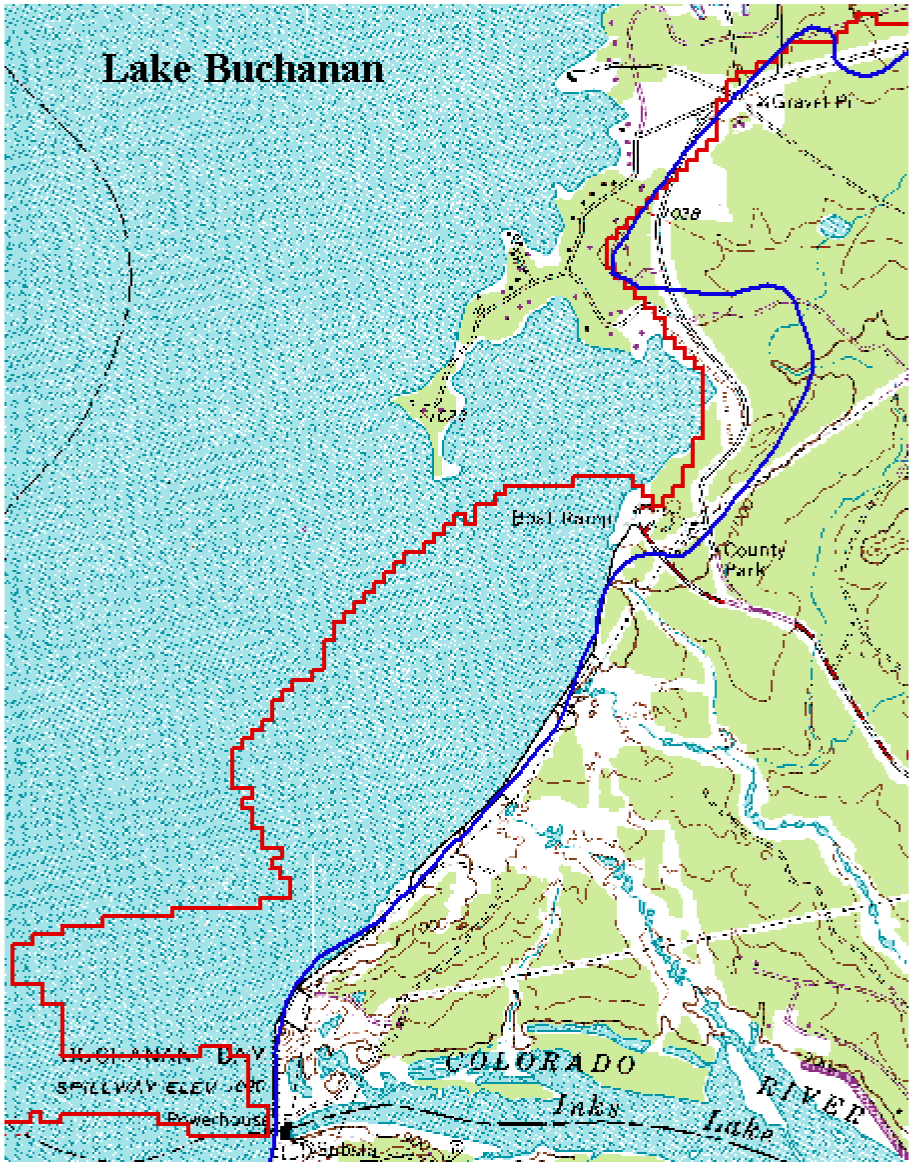



Figure 6.5. DEM-delineated boundary (red) and original boundary (blue) at mouth of Lake Buchanan

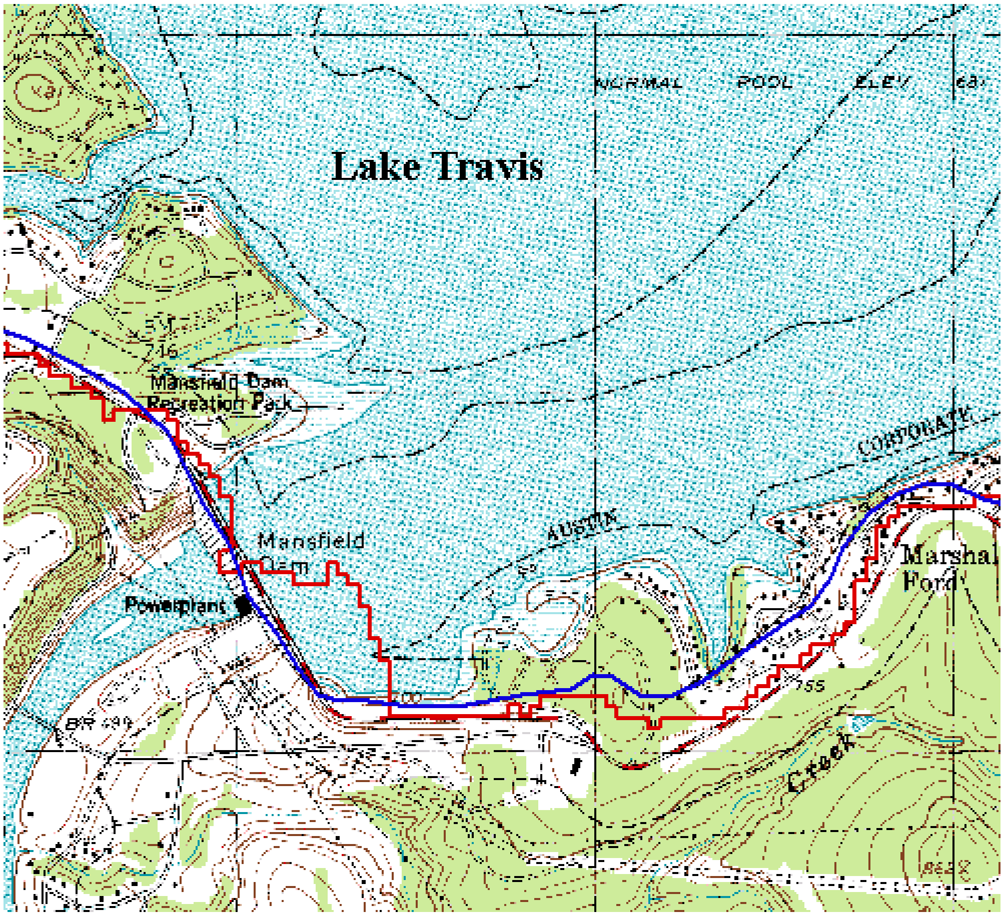



Figure 6.6. DEM-delineated boundary (red) and original boundary (blue) at mouth of Lake Travis

Figure 6.7 shows the mouth of Lake LBJ, where the DEM delineation technique produced better results than the larger-scale original delineations, although the boundaries were still slightly within the lake according to the DRGs.

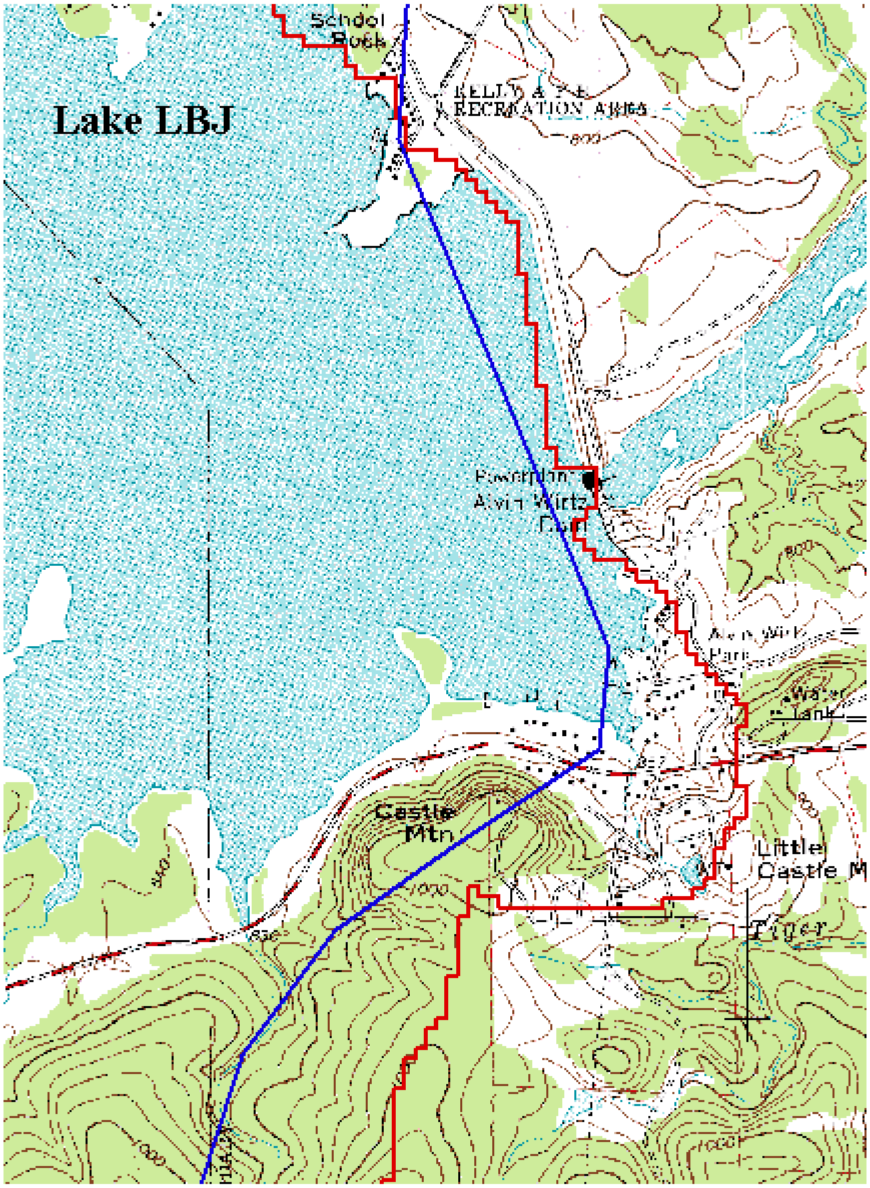



Figure 6.7. DEM-delineated boundary (red) and original boundary (blue) at mouth of Lake LBJ

Francisco Olivera at CRWR developed a process for delineating watersheds based on a flow direction grid and vector lake boundaries. The AML, or set of ArcInfo commands in Arc Macro Language, was tested for the Colorado Basin and successfully produced a set of watersheds in which the interior of each lake, as defined by the vector lake shores, was one watershed. This forced a situation where no watershed boundary crossed a lake shore.

The AML requires the input of a flow direction grid and a streams file that contains both the single-line network and the lake shorelines. This streams file must have an attribute called hydroedget populated with a 1, 2, or 3 depending on whether the edge is a normal stream, a virtual stream (stream within a lake), or a lake shore. The AML causes each segment of stream, virtual stream or shoreline to be converted to a line of outlet cells in the outlet grid. The watersheds are delineated from these outlet lines rather than from outlet points. The watersheds outside the lakes are delineated as usual, except that the cells of the flow direction grid within the lakes are assigned "no data", ensuring that none of these watersheds have drainage area within a lake. The watersheds inside the lakes are not delineated based on the flow direction grid, but instead by equally dividing the drainage area between outlets with a cost allocation function. See Appendix F for the text of the catchment AML.

The results of the catchment AML test were not included in the project deliverables because of time constraints in adjusting the process to allow delineation from user-specified outlet points instead of from every reach in the streams file. Figure 6.8 below illustrates a conceptual example of the difference between the initial delineation results and those produced by the AML.

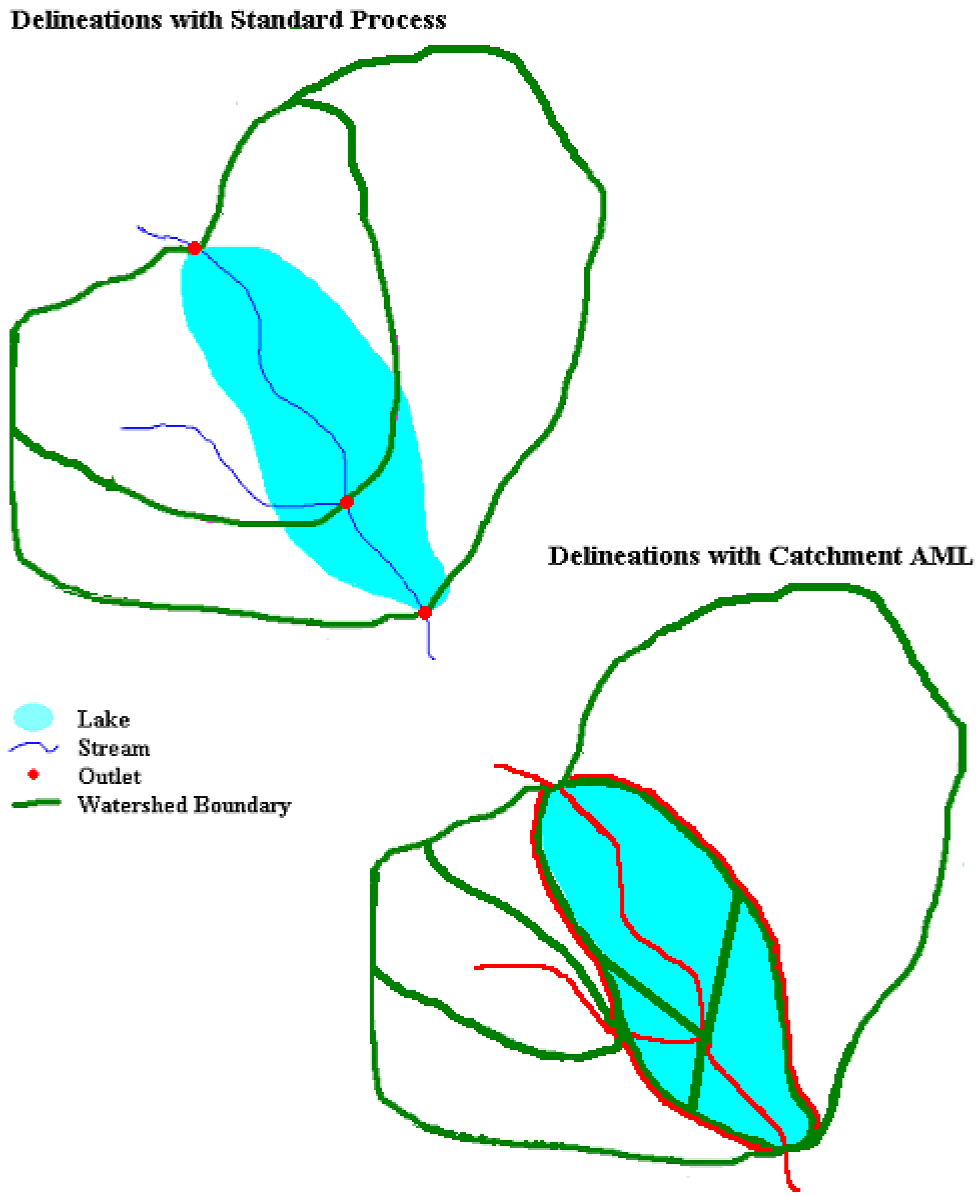



Figure 6.8. Initial watershed delineations compared to those that force boundaries at lake shores

The areas of the merged DEM-delineated watersheds were compared to the areas of the 22 corresponding original watersheds. The plot in Figure 6.9 was created to determine whether either of the two sets of delineations produced watersheds that were systematically larger or smaller than the other. There is a slight tendency for the DEM-delineated watersheds to be larger than the original watersheds. The plot also shows that, in absolute terms, the difference in area between any set of two watersheds is about as large for the small watersheds as it is for the large watersheds. These differences in area is more significant for the small watersheds.

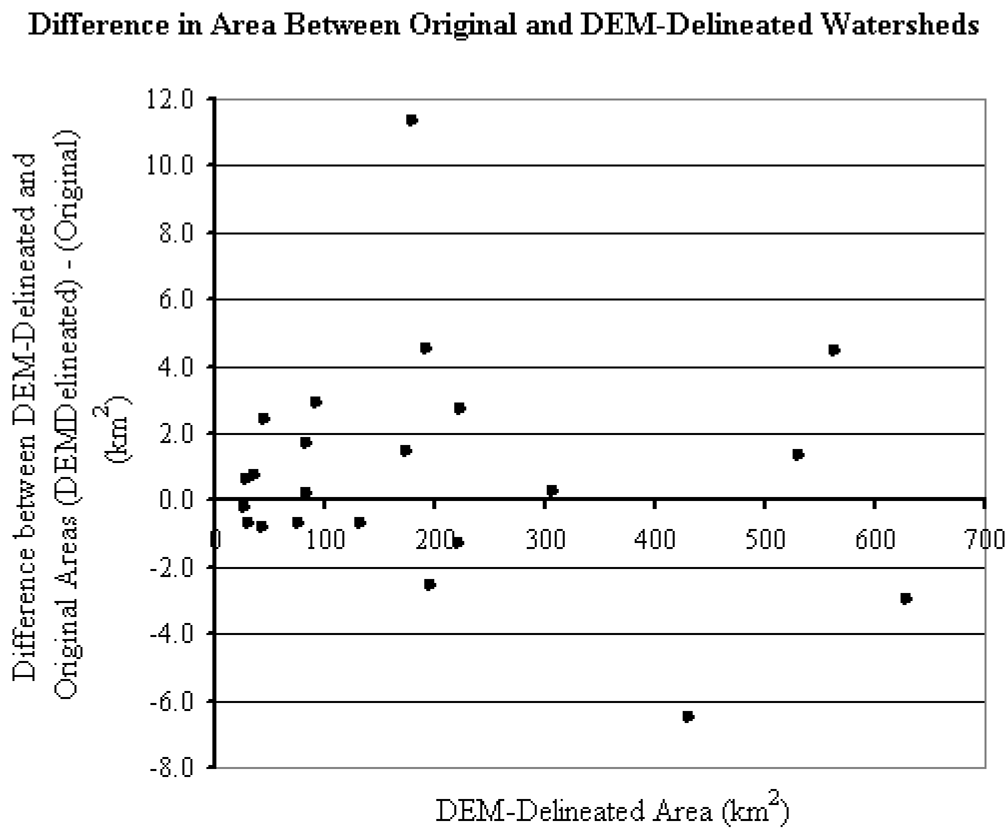



Figure 6.9. Difference between DEM-delineated and original watershed areas plotted against DEM-delineated area

## 6.4 A PRELIMINARY HYDROLOGIC MODEL

The hydrologic model created contains more detailed watershed boundaries than any previous model of the entire Colorado River basin. The HEC-HMS basin file is attributed with a watershed identification number, watershed area and initial and constant loss. An additional table contains, for each watershed, the longest flow path, the longest flow path from the centroid to the outlet, the average slope, the percent urbanization, and the percent impervious cover. Stream lengths are contained in an additional table.

In this study, all available attributes were not transferred to the basin file during its creation. It is highly recommended that they all be transferred when the basin file is created, because there is currently no easy way to add them into the basin file after its creation.

The new stream network with a 35 square mile drainage threshold contains fewer tributaries and nodes than the stream network with a one square mile drainage threshold. The less detailed stream network is more effective in an HEC-HMS model because the reaches within each watershed are not broken into small pieces by all the intersections with tributaries. A model of a few long streams is better than a model that treats the system as several short streams in succession.

Even with the larger drainage threshold, some very short streams are defined in the HEC-HMS model. They were caused by points of interest placed very close to stream junctions but not exactly on them. It is recommended that the "lag method" for flow routing be used for these streams.

## 6.5 ARCGIS HYDRO DATA MODEL

The data layers that make up the complete geodatabase for the study were imported into ArcGIS, and the data model schema was applied to the data. This represents one of the most complete basin-wide geodatabases to date that has been put into the ArcGIS Hydro Data Model framework.

The four feature datasets in the model, Hydro Features, Drainage Areas, Channels, and Hydro Network were all used, as well as one additional feature dataset called User Features. The shapefiles loaded into each of the feature datasets of the data model and a brief description of each are listed in Appendix G. Files loaded into the model and not mentioned in this thesis were either created for the Digital Flood Insurance Rate Map study or for preliminary investigational studies. The Hydro Features feature dataset contains the original stream network, points of interest used for delineation, waterbodies, and a radar-rainfall grid. The Drainage Areas feature dataset contains catchments and watersheds, the DEM-delineated streams, the centered seed points from which watersheds were delineated. The Channels feature dataset contains channel centerlines, banks, flowlines, and cross sections that were compiled for the DFIRM project and for a preliminary channel study. The Hydro Network feature dataset contains an ArcGIS 8.1 network built from the streams and watershed outlet points. The User Features feature dataset contains the *symp* and *syml* files created by CRWR-PrePro during HEC-HMS basin file creation and some additional LCRA surveyed cross section data used for a preliminary channel study.

# CHAPTER 7: CONCLUSIONS

A detailed methodology has been presented for using a variety of standard and specialized data sources to construct a comprehensive geodatabase for the Lower Colorado River basin and create a preliminary flood hydrology model from the geodatabase. The streams were compiled from the National Hydrography Dataset and edited by replacing important reaches with smaller scale creeks data produced by the Capital Area Planning Council and the City of Austin and digitizations based on the USGS Digital Orthophoto Quarter-Quadrangles and USGS Digital Raster Graphics Quadrangles. The main stem of the Colorado was attributed with National Hydrography Dataset reach codes for reach reference purposes. A measure system was implemented along the reaches. The National Elevation Dataset was used in conjunction with the stream network to delineate watersheds. Watershed outlets came from stream confluences, intersections of USGS hydrologic cataloging units with streams, bridges in the Texas Department of Transportation county roads coverages, LCRA gage locations, and points selected specifically for the shapes and sizes of watersheds they would produce. Parameters for hydrologic modeling were determined for each of the watersheds from the National Land Cover Dataset, a Lower Colorado River Authority land cover dataset, STATSGO soils data, and the streams and watershed topology. The parameters were transferred to an HEC-HMS basin file, which will be calibrated and used for hydrologic modeling in conjunction with hydraulic modeling for floodplain delineation.

The first research objective, preparation of a single line steam network in the basin, was successfully completed when the network met accuracy standards and was ready to be used in watershed delineation. The network will be used by multiple branches of the LCRA for purposes in addition to flood control, such as water quality studies. To create a standardized system for referencing segments of the Colorado River, reach codes from the National Hydrography Dataset reach coding system were transferred to the Colorado River centerline. In preparation for use in flood damage assessment, measurements from the outlet were assigned to every vertex using tools in the new GIS environment, ArcGIS 8.1.

Since ArcGIS 8.1 is available, the initial stream editing to check for and fix gaps and loops can now be performed in ArcMap. Gaps can be found by building a network, setting network flow direction, and tracing along the reaches. The can be fixed by using the snapping capabilities of ArcMap. Sometimes, after a gap is fixed by snapping, the connectivity of the network is not recognized by ArcMap until the streams are converted to a coverage, cleaned, and the rebuilt into a network. Caution must be exercised when cleaning a network since the clean process can move the lines. Cleaning the Colorado stationing line moves the line by about 1 foot ground distance.

An absolute measurement system rather than a relative measurement system was used for measure assignment even though use of an absolute measurement system in a network with reaches of a variety of scales requires extra attention to scale when using the measures. A relative measurement system would have provided meaningless measures because the network underwent extensive editing, creating a situation where the endpoints of the reaches are in arbitrary locations. Measurements based on these arbitrary endpoints would not have been useful. A potential solution is to use the NHD reach endpoints for relative measurement. This would require additional editing to the stream network to break edited reaches at the NHD endpoints, and reconnect any reaches broken between the NHD endpoints. Besides the time this editing would take, it would also introduce potential confusion about using an NHD measurement system with reaches that are not from the NHD. It is recommended, when creating a linear referencing system, that the method of linear referencing be decided before the compilation of the stream network to avoid such problems.

Previous researchers warn that breaking a line in many places increases the overall file size, and adding nodes increases the line's total length. Both of these effects were observed as a result of the NHD reach code transfer method used in this research. It was also observed that the addition of nodes on a line slightly alters its shape, making it bend up to a foot away from its original course in some places. While the small shape distortions and increased line length and file size do not pose a significant threat to the success of the floodplain delineation work, they could potentially cause serious setbacks in other projects. The necessity of transferring an attribute such as NHD reach codes from one set of lines to another must be carefully considered.

A potential way to transfer the attributes without length distortion is to edit the NHD vertices, placing them directly over the line to which reach codes are to be transferred. In this process, a vertex from the NHD line must be placed on every vertex in the preferred line, and remaining vertices of the NHD line must be placed on edges of the preferred line. The edited NHD line will be spatially exactly the same as the preferred line, but it will have its own attributes. ArcMap allows snapping of vertices of a line to vertices or edges of another line. The NHD line being moved will generally have fewer vertices than the line it is being placed over. To create an exact match over the preferred line, many vertices will need to be added to the NHD line, and then a procedure will have to be developed to do the snapping automatically, to keep editing time requirements reasonable. The “reshape shared boundary” procedure described in the ArcGIS Desktop Help allows an ArcMap user to reshape one line over another by clicking on every vertex of the preferred line while using the “reshape feature” task and the “shared edit” tool. The “reshape shared boundary” procedure may be a good starting point for further investigation.

The second research objective was to use stream and elevation data to delineate watersheds within the study area. CRWR-PrePro and its methods were used to successfully complete this objective. Watershed delineations were done by burning 1:100,000 scale streams into 1:24,000 scale DEM. With these scales of input data, much of the quality control recommended by Mason and Maidment (2000) and Hudgens and Maidment (1999) is unnecessary. Since the stream network is of a larger scale than the DEM, a thorough check for short-circuiting is not necessary. Each of the watershed areas is at least 15 times larger than Mason’s 0.15 square mile suggested threshold for manually checking watershed boundaries against DRGs. For that reason, a comprehensive comparison of watershed boundaries to DRGs was not done. A comparison of DEM-delineated watershed areas to the previous watershed areas used by the LCRA, improved 1:500,000 scale USGS watersheds, revealed that the biggest difference in size between two of the areas is 11.4 square kilometers for the 179 square kilometer watershed at the furthest downstream section of the basin. The biggest relative difference in size between two of the areas is 6.33 percent, for the same 179 square kilometer watershed.

Average slope of the longest flow path is less than 0.002 for 20 of the 232 watersheds for which attributes were calculated. If the watershed boundaries in these areas of low slope are to play an important role in small-scale studies, it is recommended that the boundaries be checked for accuracy. It is difficult to check the boundaries against the DRGs because of lack of contour lines in the flat areas.

The stream buffering process used by Mason and Maidment (2000) was not used in this study, and so watershed boundaries at the basin's edge should be checked if they are to be used for small-scale studies where this level of accuracy would be needed.

Errors were discovered in the watershed delineation when watershed boundaries passed near lake shores. These errors are caused by DEMs that do not correctly reflect the terrain sloping towards the lake shore or the continued slope of the lake bottom towards the deepest part. A method for delineating the watersheds inside and outside of lakes separately and then merging the results into one final delineation is presented. The method was tried in the Colorado basin and successfully produced a set of watersheds delineated from every stream confluence that did not cross lake shores.  Lakes are often significant enough features in a geodatabase that even if the error in watershed shape near lake outlets would not normally be important, it becomes important because of the proximity to a lake.  For future watershed delineation projects of this scale it is suggested that an informed decision be reached about the need for accurate delineations around lake shores, and if extra accuracy around lake shores is needed, a process similar to the AML presented in this thesis be used to account for the shores.

The third research objective, calculation of parameters for the 232 watersheds, was successfully completed using a combination of CRWR-PrePro, HEC-GeoHMS, and ArcInfo commands.  Parameters that vary across the watershed such as initial and uniform losses were averaged for each watershed. Stream lengths were also calculated.

When combining land use data from several sources, for a more consistent curve number grid, it is suggested that one of the land use classification systems be "translated" in to the other land use classification system rather than having a separate set of curve numbers for each.  Having different sets of curve numbers in two parts of a basin may introduce systematic bias, treating very similar land uses as hydrologically very different.  It would be better to recognize that two land uses from different data sets with a slightly different classification, such as "fallow" and "bare lands" are likely to be the same.

An HEC-HMS model was built for the upper and lower portions of the study area from the streams, watersheds and attributes, completing the fourth research objective. The hydrologic model will be calibrated from gage data, and will be used in conjunction with a hydraulic model of the Colorado and its major tributaries to predict flood inundation levels in these areas.

A difference between this study and many of the previous studies of the CRWR-PrePro method for hydrologic model creation is that the model created in this study is not just a research exercise. It is the backbone for the primary model that a major river management organization will use to make decisions involving large amounts of money and the public's safety. Hopefully, by presenting some observations and recommendations learned from creation of this model, similar efforts will be facilitated for others working without the resources or flexibility of a research setting.

# APPENDIX A: CURVE NUMBER AND UNIFORM LOSS RATE LOOKUP TABLES

This appendix contains the text of the curve number and uniform loss rate lookup tables used in this project. The lucode field contains the land use code, and the hyd_a, hyd_b, hyd_c, and hyd_d fields contain curve numbers or uniform loss rates for each of the four hydrologic soil groups.

## A.1 CURVE NUMBER LOOKUP TABLE

Table A.1. Curve Number Lookup Table

| lucode | Land Use | Detail | hyd_a | hyd_b | hyd_c | hyd_d |
|---|---|---|---|---|---|---|
| 0 | No Data | assume grasslands | 39 | 61 | 74 | 78 |
| 3 | High Intensity Urban | | 89 | 92 | 94 | 95 |
| 4 | Low Intensity Urban/Rural Developed | | 69 | 80 | 86 | 89 |
| 5 | Golf Courses and Parks | | 42 | 63 | 75 | 81 |
| 10 | Cultivated Lands | soybeans, cotton, alfalfa | 61 | 70 | 77 | 80 |
| 11 | Cultivated Lands - Flooded | | 100 | 100 | 100 | 100 |
| 20 | Grasslands | | 39 | 61 | 74 | 78 |
| 32 | Broad-leaved Deciduous Forest | | 36 | 60 | 73 | 79 |
| 36 | Cedar | | 30 | 55 | 70 | 77 |
| 37 | Pine Forest | | 32 | 58 | 72 | 79 |
| 48 | Woodland/Shrubland | | 30 | 55 | 70 | 77 |
| 50 | Bare Lands | | 77 | 86 | 91 | 94 |
| 60 | Wetlands | | 30 | 48 | 65 | 73 |
| 61 | Unconsolidated Shore | | 100 | 100 | 100 | 100 |
| 64 | Saline Emergent Wetlands | | 30 | 48 | 65 | 73 |
| 65 | Saline Woody Wetlands | | 30 | 48 | 65 | 73 |
| 66 | Fresh Emergent Wetlands | | 30 | 48 | 65 | 73 |
| 68 | Fresh Woody Wetlands | | 30 | 48 | 65 | 73 |
| 70 | Water and Submerged Lands | | 100 | 100 | 100 | 100 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 100 | No Data | all cells in Gulf, assume water | 100 | 100 | 100 | 100 |
| 111 | Open Water | | 100 | 100 | 100 | 100 |
| 121 | Low Intensity Residential | | 61 | 75 | 83 | 87 |
| 122 | High Intensity Residential | | 77 | 85 | 90 | 92 |
| 123 | Commercial/Industrial/Transportation | | 89 | 92 | 94 | 95 |
| 131 | Bare Rock/Sand/Clay | | 77 | 86 | 91 | 94 |
| 132 | Quarries/Strip Mine/Gravel Pits | | 77 | 86 | 91 | 94 |
| 133 | Transitional | | 77 | 86 | 91 | 94 |
| 141 | Deciduous Forest | | 36 | 60 | 73 | 79 |
| 142 | Evergreen Forest | | 32 | 58 | 72 | 79 |
| 143 | Mixed Forest | | 30 | 55 | 70 | 77 |
| 151 | Shrubland | | 30 | 55 | 70 | 77 |
| 161 | Orchards/Vineyards/Other | | 32 | 58 | 72 | 79 |
| 171 | Grasslands/Herbaceous | | 39 | 61 | 74 | 78 |
| 181 | Pasture/Hay | | 39 | 61 | 74 | 78 |
| 182 | Row Crops | | 67 | 78 | 85 | 89 |
| 183 | Small Grains | | 63 | 75 | 83 | 87 |
| 184 | Fallow | | 76 | 85 | 90 | 93 |
| 185 | Urban/Recreational Grasses | | 49 | 69 | 79 | 84 |
| 191 | Woody Wetlands | | 30 | 48 | 65 | 73 |
| 192 | Emergent Herbaceous Wetlands | | 30 | 48 | 65 | 73 |

## A.2 UNIFORM LOSS RATE LOOKUP TABLE

Table A.2. Uniform Loss Rate Lookup Table (inches/hour)

| lucode | Land Use | Detail | hyd_a | hyd_b | hyd_c | hyd_d |
|---|---|---|---|---|---|---|
| 0 | No Data | assume grasslands | 0.41 | 0.22 | 0.12 | 0.09 |
| 3 | High Intensity Urban | | 0.06 | 0.03 | 0.02 | 0.01 |
| 4 | Low Intensity Urban/Rural Developed | | 0.21 | 0.11 | 0.06 | 0.05 |
| 5 | Golf Courses and Parks | | 0.39 | 0.21 | 0.11 | 0.09 |
| 10 | Cultivated Lands | soybeans, cotton, alfalfa | 0.2 | 0.12 | 0.07 | 0.05 |
| 11 | Cultivated Lands - Flooded | | 0 | 0 | 0 | 0 |
| 20 | Grasslands | | 0.41 | 0.22 | 0.12 | 0.09 |
| 32 | Broad-leaved Deciduous Forest | | 0.44 | 0.22 | 0.13 | 0.09 |
| 36 | Cedar | | 0.53 | 0.26 | 0.15 | 0.11 |
| 37 | Pine Forest | | 0.47 | 0.24 | 0.14 | 0.09 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 48 | Woodland/Shrubland | | 0.43 | 0.22 | 0.13 | 0.09 |
| 50 | Bare Lands | | 0.1 | 0.02 | 0.01 | 0.01 |
| 60 | Wetlands | | 0.5 | 0.24 | 0.17 | 0.14 |
| 61 | Unconsolidated Shore | | 0 | 0 | 0 | 0 |
| 64 | Saline Emergent Wetlands | | 0.5 | 0.24 | 0.17 | 0.14 |
| 65 | Saline Woody Wetlands | | 0.5 | 0.24 | 0.17 | 0.14 |
| 66 | Fresh Emergent Wetlands | | 0.5 | 0.24 | 0.17 | 0.14 |
| 68 | Fresh Woody Wetlands | | 0.5 | 0.24 | 0.17 | 0.14 |
| 70 | Water and Submerged Lands | | 0 | 0 | 0 | 0 |
| 100 | No Data | all cells in Gulf, assume water | 0 | 0 | 0 | 0 |
| 111 | Open Water | | 0 | 0 | 0 | 0 |
| 121 | Low Intensity Residential | | 0.25 | 0.14 | 0.07 | 0.06 |
| 122 | High Intensity Residential | | 0.14 | 0.08 | 0.04 | 0.03 |
| 123 | Commercial/Industrial/Transportation | | 0.06 | 0.03 | 0.02 | 0.01 |
| 131 | Bare Rock/Sand/Clay | | 0.1 | 0.02 | 0.02 | 0.01 |
| 132 | Quarries/Strip Mine/Gravel Pits | | 0.11 | 0.06 | 0.04 | 0.03 |
| 133 | Transitional | | 0.11 | 0.06 | 0.04 | 0.03 |
| 141 | Deciduous Forest | | 0.44 | 0.22 | 0.13 | 0.09 |
| 142 | Evergreen Forest | | 0.53 | 0.18 | 0.11 | 0.08 |
| 143 | Mixed Forest | | 0.4 | 0.2 | 0.12 | 0.08 |
| 151 | Shrubland | | 0.4 | 0.2 | 0.12 | 0.08 |
| 161 | Orchards/Vineyards/Other | | 0.36 | 0.18 | 0.11 | 0.08 |
| 171 | Grasslands/Herbaceous | | 0.41 | 0.22 | 0.12 | 0.09 |
| 181 | Pasture/Hay | | 0.41 | 0.22 | 0.12 | 0.09 |
| 182 | Row Crops | | 0.18 | 0.11 | 0.07 | 0.05 |
| 183 | Small Grains | | 0.2 | 0.12 | 0.07 | 0.05 |
| 184 | Fallow | | 0.11 | 0.06 | 0.04 | 0.03 |
| 185 | Urban/Recreational Grasses | | 0.31 | 0.16 | 0.09 | 0.07 |
| 191 | Woody Wetlands | | 0.47 | 0.24 | 0.14 | 0.09 |
| 192 | Emergent Herbaceous Wetlands | | 0.5 | 0.24 | 0.17 | 0.14 |

# APPENDIX B: FEATURE DATASET REFERENCE FRAME PARAMETERS

This appendix contains the reference frame parameters used for the ArcGIS 8.1 feature class containing Colorado basin data. The precision values specify the degree of resolution available, or the number of system units per unit of measure.

Projected Coordinate System:
    Name: NAD_1983_StatePlane_Texas_Central_FIPS_4203_Feet
        Alias:
        Abbreviation:
        Remarks:
    Projection: Lambert_Conformal_Conic
    Parameters:
        False_Easting: 2296583.333333
        False_Northing: 9842500.000000
        Central_Meridian: -100.333333
        Standard_Parallel_1: 30.116667
        Standard_Parallel_2: 31.883333
        Latitude_Of_Origin: 29.666667
    Linear Unit: Foot_US (0.304801)

Geographic Coordinate System:
    Name: GCS_North_American_1983
    Alias:
    Abbreviation:
    Remarks:
    Angular Unit: Degree (0.017453292519943295)
    Prime Meridian: Greenwich (0.000000000000000000)
    Datum: D_North_American_1983
        Spheroid: GRS_1980
            Semimajor Axis: 6378137.000000000000000000
            Semiminor Axis: 6356752.314140356100000000

Inverse Flattening: 298.257222101000020000

X/Y Domain:
Min X: 1000000.000000
Min Y: 9200000.000000
Max X: 4000000.000000
Max Y: 12200000.000000
Scale: 715.827882

M Domain:
Min: -100.000000
Max: 4000000.000000
Scale: 536.857490

Z Domain:
Min: -30.000000
Max: 250000.000000
Scale: 8588.903912

# APPENDIX C: LINEAR REFERENCING CALCULATION

This appendix contains the commands used to calculate measures on the shape field of the stream network feature class. The 3280.84 is a conversion factor between feet and kilometers.

**Pre-Logic VBA Script Code**

```
dim pMSeg as IMSegmentation
set pMSeg = [Shape]
If [FlowDirection] = 1 then
pMSeg.SetAndInterpolateMsBetween (([LengthDownstream]+
        [ShapeLength] )/3280.84), ( [LengthDownstream]/3280.84)
elseif [FlowDirection] =2 then
pMSeg.SetAndInterpolateMsBetween
([LengthDownstream]/3280.84), ((
        [LengthDownstream] + [ShapeLength])/3280.84)
Else
pMSeg.SetAndInterpolateMsBetween 0, 1
Endif
dim pGeom as IGeometry
set pGeom = pMSeg
```

**Shape =**

```
pGeom
```

# APPENDIX D: PROJECTION FILES

This appendix contains the text of the projection files that were used in the project.

## D.1 GEOGRAPHIC TO STATE PLANE, TEXAS CENTRAL ZONE

```
input
Projection GEOGRAPHIC
Units DD
Datum NAD83
Parameters
output
Projection Stateplane
Units meters
Zone 5376
Datum NAD83
Parameters
End
```

## D.2 ALBERS TO STATE PLANE, TEXAS CENTRAL ZONE

```
input
Projection albers
Spheroid GRS1980
Datum NAD83
Units meters
Parameters
29 30 0
45 30 0
-96 0 0
23 0 0
0
0
```

output
Projection Stateplane
Units meters
Zone 5376
Datum NAD83
Parameters
End

## D.3 STATE PLANE, FEET TO STATE PLANE, METERS

input
Projection Stateplane
Units feet
Zone 5376
Datum NAD83
Parameters
output
Projection Stateplane
Units meters
Zone 5376
Datum NAD83
Parameters
End

# APPENDIX E: DATA DICTIONARY

This appendix contains a list of the contents of each of the CD's transferred to the LCRA from CRWR on December 19, 2000. Four CDs were transferred, called CRWR-PrePro Hydrologic Model of the Lower Colorado River Basin, Elevation Data 1, Elevation Data 2, and Land and Soils. A brief description of each and the contents follow.

## E.1 CRWR-PrePro Hydrologic Model of the Lower Colorado River Basin

This CD contains the skeleton HMS model consisting of the HMS map and basin files, Excel tables with the watershed parameters calculated in Section 5.3.2 and the lengths of the reaches in the HMS schematic, and lookup tables used to calculate curve numbers and uniform loss rates. The GIS stream and watershed shapefiles used to create the basin files are also on this CD, as well as three detailed memos written for the LCRA describing the data development process and a memo with the CD contents.

A folder called Supporting_GIS_grids contains some of the supporting GIS data used in developing the watersheds and their parameters. The folder contains grids of curve numbers and constant infiltration rates and the grids created during the delineation of the 100,000 cell drainage threshold streams and watersheds that were used for the HMS schematic. All grids are in State Plane, 1983 datum, meters.

The contents are as follows.

***CD Contents Memo.doc*** **–** memo describing each of the files on each of the CDs
***File list-readme.txt*** **–** a brief list of the files on this CD

***Co_lower_1207.basin*** **-** HMS basin file for lower subbasin
***Co_upper_1207.basin*** **-** HMS basin file for upper subbasin

***basin_attributes.bmp*** **-** picture showing close-up of lower basin file in HMS showing attributes
***lower_schematic.bmp*** **-** picture showing what the lower basin file looks like opened in HMS
***upper_schematic.bmp*** **-** picture showing what the upper basin file looks like opened in HMS

***lower_hms_map.map*** **-** map file for lower subbasin
***upper_hms_map.map*** **-** map file for upper subbasin

***poi_delstr_l_sp83f_1204*** **–** 100,000 cell drainage threshold DEM-delineated stream network, lower subbasin
***poi_delstr_u_sp83f_1204*** **-** 100,000 cell drainage threshold DEM-delineated stream network, upper subbasin
***poi_wtrshd_l_sp83f_1204*** **-** 100,000 cell drainage threshold DEM-delineated stream network, lower subbasin
***poi_wtrshd_u_sp83f_1204*** **-** 100,000 cell drainage threshold DEM-delineated stream network, upper subbasin

***wshd_parameters.xls*** **–** table of watershed parameters
***str_lengths.xls*** **–** table of lengths of streams in HMS basin files

***lcralookup_cn.txt*** **-** curve number versus land use and soil lookup table
***lcralookup_constinf.txt*** **-** constant infiltration rate versus land use and soil lookup table

***co_lower_1207.htm*** **-** metadata
***co_upper_1207.htm*** **-** metadata
***poi_delstr_l_sp83f_1204.htm*** **-** metadata
***poi_delstr_u_sp83f_1204.htm*** **-** metadata
***poi_wtrshd_l_sp83f_1204.htm*** **-** metadata
***poi_wtrshd_u_sp83f_1204.htm*** **-** metadata

***all Data Tracking Sheets.doc*** **-** many LCRA data tracking sheets, used for file transfer to LCRA

***Creation Process for Single Line Representation.doc*** **-** technical memo to LCRA describing process
***Delineation Process for Watersheds.doc*** **-** technical memo to LCRA describing process
***Creation of HEC-HMS Basin File.doc*** **-** technical memo to LCRA describing process

**Supporting_GIS_grids – folder**
***cn_lcra4.zip*** **–** grid of curve numbers
***constinf_lcra3.zip*** **–** grid of constant infiltration rates

***1204gridsl.zip*** **–** a zip file containing the following grids for the lower subbasin
***1204linkl*** **–** initial links grid for the 100,000 cell threshold delineations
***1204modlinkl*** **–** modified links grid for the 100,000 cell threshold delineations
***1204modoutl*** - modified outlets grid for the 100,000 cell threshold delineations
***1204outl*** **–** initial outlets grid for the 100,000 cell threshold delineations
***1204wtrshdl*** **–** watershed grid for the 100,000 cell threshold delineations
***1204gridsu.zip*** **–** a zip file containing the same grids as 1204gridsl.zip, but for the upper subbasin

## E.2 ELEVATION DATA 1

This CD contains elevation data and processed elevation data that was used to delineate all the watersheds in the study. All grids are in State Plane, 1983 datum, meters.

The contents are as follows.

**Lower_Subbasin - folder**
***Cofdr_l.zip*** **–** flow direction grid for the lower subbasin
***Cofil_l.zip*** **–** filled DEM for the lower subbasin
***Flacc_l.zip*** **–** flow accumulation grid for the lower subbasin
***Burndem_l.zip*** **–** burned DEM for the lower subbasin

**DEM - folder**

*Co_lower.zip* **–** DEM for the lower subbasin

**Upper_Subbasin – folder**

*Burndem_u.zip* **–** burned DEM for the upper subbasin

**DEM - folder**

*Co_upper.zip* **-** DEM for the upper subbasin

## E.3 ELEVATION DATA 2

This CD contains more processed elevation data that was used to delineate all the watersheds in the study. All grids are in State Plane, 1983 datum, meters.

The contents are as follows.

**Upper_Subbasin - folder**

*Cofdr_l.zip* **–** flow direction grid for the upper subbasin
*Cofil_l.zip* **–** filled DEM for the upper subbasin
*Flacc_l.zip* **–** flow accumulation grid for the upper subbasin

## E.4 LAND AND SOILS

This CD contains mostly soil and land use data used in defining parameters for the watersheds. There are also shapefiles of the watershed centroids and longest flow paths used for watershed parameter definition; grids of areas of impervious cover and urban areas; the original vector stream network; and the 2878 cell drainage threshold DEM-delineated streams, 232 watersheds and points of interest including gages and HUC intersections from which these watersheds were delineated. All grids are in State Plane, 1983 datum, meters.

The shapefiles in the Centroids_longest_flowpaths folder are in meters. Other shapefiles are in feet or meters, as specified by an "f" or an "m" in the file name.

The contents are as follows.

**Cenroids_longest_flowpaths - folder**

***centrfp_1.dbf* –** centroidal flow paths for the lower subbasin
***centrfp_1.shp* –** centroidal flow paths for the lower subbasin
***centrfp_1.shx* –** centroidal flow paths for the lower subbasin
***centrfp_u.dbf* –** centroidal flow paths for the upper subbasin
***centrfp_u.shp* –** centroidal flow paths for the upper subbasin
***centrfp_u.shx* –** centroidal flow paths for the upper subbasin
***lfp_cent_1.dbf* –** centroids for the lower subbasin determined by the longest flow path method
***lfp_cent_1.shp* –** centroids for the lower subbasin determined by the longest flow path method
***lfp_cent_1.shx* –** centroids for the lower subbasin determined by the longest flow path method
***lfp_cent_u.dbf* –** centroids for the upper subbasin determined by the longest flow path method
***lfp_cent_u.shp* –** centroids for the upper subbasin determined by the longest flow path method
***lfp_cent_u.shx* –** centroids for the upper subbasin determined by the longest flow path method
***longestfp_1.dbf* –** longest flow paths for the lower subbasin
***longestfp_1.shp* –** longest flow paths for the lower subbasin
***longestfp_1.shx* –** longest flow paths for the lower subbasin
***longestfp_u.dbf* –** longest flow paths for the lower subbasin
***longestfp_u.shp* –** longest flow paths for the lower subbasin
***longestfp_u.shx* –** longest flow paths for the lower subbasin

**Impervious_and_Urbanization - folder**

***Impcov* –** grid of areas of impervious cover
***Urban* –** grid of urbanized areas
***Info* –** folder that is part of Impcov and Urban grids

**Land Cover - folder**

***Info* –** folder that is part of LCRANLCD2 grid
***LCRANLCD2* –** Land Use/Land Cover grid used for parameter determination
***Landcov.zip* –** a polygon file of the information in LCRANLCD2

**Reference_tables - folder**

***LCRAlookup_Cn.txt*** - curve number versus land use and soil lookup table

***LCRAlookup_constinf.txt*** – constant infiltration rate versus land use and soil lookup table

***Muidjoin.dbf*** – table containing percentages of each soil group in each land use/land cover polygon

**Soils – folder**

**TX – folder**

**Header - folder**

***Head.txt*** – header for Texas STATSGO soils data

***Proj.txt*** – original projection of Texas STATSGO data

**Metadata - folder**

***Metadata.txt*** – metadata for Texas STATSGO data

**Spatial - folder**

TX

***Comp.aih*** – table that comes with STATSGO data

***Comp.ain*** – table that comes with STATSGO data

***Comp.dbf*** – table that comes with STATSGO data

***Layer.dbf*** – table that comes with STATSGO data

***Mapupit.aih*** – table that comes with STATSGO data

***Mapunit.ain*** – table that comes with STATSGO data

***Mapunit.dbf*** – table that comes with STATSGO data

***Compyld.dbf*** – table that comes with STATSGO data

***TX_sp83m.dbf*** – projected STATSGO polygons

***TX_sp83m.shp*** – projected STATSGO polygons

***TX_sp83m.shx*** – projected STATSGO polygons

**Stream_watershed_shapefiles - folder**

***co_sp83f_0523.dbf*** – NHD-derived network that was burned into DEM

***co_sp83f_0523.sbn*** – NHD-derived network that was burned into DEM

***co_sp83f_0523.sbx*** – NHD-derived network that was burned into DEM

***co_sp83f_0523.shp*** – NHD-derived network that was burned into DEM

***co_sp83f_0523.shx*** – NHD-derived network that was burned into DEM

***poi_delstr_sp83f_0915.dbf*** – DEM-delineated streams with 2878 cell threshold

***poi_delstr_sp83f_0915.shp*** – DEM-delineated streams with 2878 cell threshold

***poi_delstr_sp83f_0915.shx*** – DEM-delineated streams with 2878 cell threshold

***poi_delstr_sp83f_0915.htm*** **-** metadata

***poi_sp83f_0915.dbf*** **–** 232 points of interest, gages and HUC intersections

***poi_sp83f_0915.shp*** **–** 232 points of interest, gages and HUC intersections

***poi_sp83f_0915.shx*** **–** 232 points of interest, gages and HUC intersections

***poi_sp83f_0915.htm*** **–** metadata

***poi_wtrshd_sp83f_0915.dbf*** **–** 232 watersheds delineated from points of interest, gages and HUC intersections

***poi_wtrshd_sp83f_0915.shp*** **–** 232 watersheds delineated from points of interest, gages and HUC intersections

***poi_wtrshd_sp83f_0915.shx*** **–** 232 watersheds delineated from points of interest, gages and HUC intersections

***poi_wtrshd_sp83f_0915.htm*** **-** metadata

# APPENDIX F: COMMAND LIST FOR DELINEATION INCORPORATING LAKE SHORES

This appendix contains a set of ArcInfo commands developed by Francisco Olivera at CRWR that produces a watershed delineation with watershed boundaries that do not cross lake shores.

### Catchment.aml

```
' At the ARC prompt
' The Edges should have a HydroEdgeType attribute called "hydroedget" in this
'AML
' The names of the input edges coverage and flowdirection grid should be entered
' at the beginning of the AML code
'
************************************************************************
' Input data
fdr = <your FLOWDIRECTION grid>
copy <your EDGES coverage> edges
'
************************************************************************
' Creating a polygon coverage of lakes
reselect edges lakes line
res hydroedget = 3
~
n
n
build lakes poly
'
************************************************************************
'Creating a line coverage of FlowEdges and ShoresEdges
reselect edges stsh line
res hydroedget <> 2
~
n
n
build stsh line
```

```
'
******************************************************************
' Creating a line coverage of VirtualEdges
reselect edges virtual line
  res hydroedget = 2
  ~
  n
  n
build virtual line
'
******************************************************************
' Invoking grid and defining the analysis window and cell size
grid
setwindow fdr fdr
setcell fdr
'
******************************************************************
' Creating "holes" in the flowdirection grid at the lakes
lakesgr = polygrid(lakes)
lakesgr0 = isnull(lakesgr)
fdr0 = fdr / lakesgr0

' Defining the FlowEdges and ShoreEdges as outlets
stshgr = linegrid(stsh, ObjectID)

' Delineating FlowCatchments and ShoreCatchments
wsh1 = watershed(fdr0, stshgr)
'
******************************************************************
' Delineating VirtualCatchments
virtualgr = linegrid(virtual, ObjectID)
intvirtualgr = int(virtualgr)
cost = 1
wsh2 = costallocation(intvirtualgr, cost) / (1 - lakesgr0)
'
******************************************************************
'Merging catchment
wsh = merge(wsh1, wsh2)

quit

gridpoly wsh WshPC
```

```
'
********************************************************************
' Cleaning Garbage
kill lakes all
kill stsh all
kill virtual all
kill cost all
kill fdr0 all
kill lakesgr all
kill lakesgr0 all
kill stshgr all
kill virtualgr all
kill intvirtualgr all
kill wsh1 all
kill wsh2 all

&Return
```

# APPENDIX G: FILLED ARCGIS HYDRO DATA MODEL FEATURE CLASSES

This appendix contains a list of each of the feature datasets in the ArcGIS Hydro Data Model and the feature classes within the model that were filled with Colorado basin data. The shapefile names and a brief description of each file are included.

Table G.1. Feature datasets in the ArcGIS Hydro Data Model and the data populating them

| **Feature Dataset – Hydro Features** | | |
|---|---|---|
| **Feature Class Name** | **Shapefile Name** | **Description** |
| Structure | *Waterbridges_f* | Points representing bridges from TXDOT roads coverage, snapped to DrainagePath |
| UserPoint | *Poi_sp83f_0915* | Gages, major confluences and other points specified by Halff Associates, snapped to within 30m of DrainagePath and used to delineate Watershed |
| Waterbody | *Waterbodies_f* | Outlines of major lakes |
| HydroLine | *Co_sp83f_0523* | NHD-derived stream network, with edits to main stem and major tributaries based on DOQQs and LCRA digitized centerline (*coloriv_cl*) |
| MonitoringPoint | *Hydromet_ut_07_06_2000* | LCRA current and future gage locations as of 7/6/2000 |
| HydroResponseUnit | *Nexrainpixels_sp83f* | NEXRAD grid provided to the LCRA by the NEXRAIN Corporation |

| Feature Dataset – Drainage Areas | | |
|---|---|---|
| **Feature Class Name** | **Shapefile Name** | **Description** |
| Catchment | *all_wtrshdp1_edited_sp83f* | Catchments delineated at each confluence of DrainagePath with a one square mile stream threshold |
| Watershed | *Poi_wtrshd_sp83f_0915* | Watersheds delineated from UserPoint |
| DrainagePath | *Poi_delstr_sp83f_0915* | Stream network delineated from NED data, with a one square mile stream drainage threshold |
| DrainagePoint | *Poi_sp83f_centrd_0915* | Seed points used to delineate watersheds in Watershed. They correspond to the points in *poi_sp83f_0915*, but are centered on the DEM grid cells used for watershed delineation. |
| Basin | *Cohuc_sp83f* | 8-digit HUC units |

| Feature Dataset – Channels | | |
|---|---|---|
| **Feature Class Name** | **Shapefile Name** | **Description** |
| ProfileLine | *Mck_profileline3d*<br><br>*Flowpath.shp and banks3d.shp* | 3D centerline, banks and arbitrary flowlines. Elevations come from *McKinney_TIN*, a TIN created from mass points and break lines from the LCRA<br><br>3D centerline, flowlines, and bank lines developed using GeoRAS and a TIN (*Lbj_tin*) representing Lake LBJ, the Llano River, and part of Sandy Creek created from UNET cross sections, 2-ft contour data from aerial photos, and 30 m DEM |
| CrossSection | *Mck_extracted_crs_secs3D5*<br><br>*Xscultines3d.shp* | Cross sections extracted from *McKinney_TIN*<br><br>3D cross sections extracted from *Lbj_tin* |

| Feature Dataset – Hydro Network | | |
|---|---|---|
| **Feature Class Name** | **Shapefile Name** | **Description** |
| HydroJunction | No Shapefile | Created by first creating a temporary network with HydroEdge, saving new junctions as HydroJunction, and deleting the network. HydroJunction is all the junctions in the shapefile *co_sp83f_0523*. |
| HydroEdge | *Co_sp83f_0523* | Edges used for network |
| HydroNetwork | No shapefile | Network with DrainagePoint, HydroJunction and HydroEdge |
| HydroNetwork_Junctions | No shapefile | New junctions created when network was created |

| Feature Dataset – User Features | | |
|---|---|---|
| **Feature Class Name** | **Shapefile Name** | **Description** |
| SchematicLine | *Syml_f* | Schematic lines created by Pre-Pro for import into HEC-HMS |
| SchematicPoint | *Symp_f* | Schematic points created by Pre-Pro for import into HEC-HMS |
| Surveyed_elevations | *Surveyed_crs* | Points and elevations from the LCRA |

# REFERENCES


ADR, Inc., 2001. *Metadata: Riverfront Waterbodies Data.* ADR, Inc., Pennsauken, New Jersey.

Ahrens, S. and D. Maidment, 1999. CRWR Online Report 1999-6: *Flood Forecasting for the Buffalo Bayou using CRWR-Pre-Pro and HEC-HMS.* Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

Anderson, D., 2000. CRWR Online Report 2000-11: *GIS-Based Hydrologic and Hydraulic Modeling for Floodplain Delineation at Highway River Crossings.* Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

Andrysiak, P. and D. Maidment, 2000. CRWR Online Report 2000-4: *Visual Floodplain Modeling with Geographical Information Systems (GIS).* Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

Asante, K., D. Maidment, J. Famiglietti, and F. Olivera, 2000. CRWR Online Report 2000-1: *Approaches to Continental Scale River Flow Routing.* Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

CAPCO, 2001. *GIS Data.* Internet Site: http://www.capco.state.tx.us/GISDatapage.htm

CAPCO, 2001. *Imagery.* Internet Site: http://www.capco.state.tx.us/imagery.htm

CAPCO, 2001. *Planimetric Linework.* Internet Site: http://www.capco.state.tx.us/planimetrics.htm

Davis, K., 1999. *River Network Preparation*, GIS Hydro ’99 - Watershed Characterization Module. Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

Dunn, C., C. Ackerman, J. Doan, and T. Evans, 2000. *Hydrologic Modeling for the Sacramento and San Joaquin Basins Using GeoHMS,* Proceedings from the 20th ESRI International User Conference, San Diego, California. U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.

EISYS, 1998. *Metadata: lc_metadata.* EISYS, Fort Collins, Colorado.

Hargrove, W., R. Winetrfield, and D. Levine, 1995. *Dynamic Segmentation and Thiesen Polygons: A Solution to the River Mile Problem.* Proceedings from the 15th ESRI International User Conference, Palm Springs, California.

Hudgens, B. and D. Maidment, 1999. CRWR Online Report 99-4: *Geospatial Data in Water Availability Modeling*. Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

LCRA, 1993. *Metadata: Colorado River 1:100,000 (lakes).* LCRA, Austin,Texas.

LCRA, 2001. *About the LCRA.* Internet Site: http://www.lcra.org/about

Maidment, D. and F. Olivera, 1999. *Project Proposal: Flood Mapping in the Lower Colorado River.* Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

Mason, D. and D. Maidment, 2000. CRWR Online Report 2000-3: *An Analysis of a Methodology for Generating Watershed Parameters using GIS.* Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

McPherson, M. and H. Henneman, 2000. *DEM Processing for Hydrologic Modeling Studies*, Proceedings from the 20th ESRI International User Conference, San Diego, California. U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.

Olivera, F. and D. Maidment, 1999. *GIS Tools for HMS Modeling Support.* In Hydraulic and Hydrologic Modeling Support, ed. By D. Maidment and D. Djokic, Environmental Systems Research Institute, Redlands, California. 85-112.

Osborne, K., M. Barrett, and D. Maidment, 2000. CRWR Online Report 2000-10: *A Water Quality GIS Tool for the City of Austin Incorporating Non*

*Point Sources and Best Management Practices*. Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

Tate, E., F. Olivera, and D. Maidment, 1999. CRWR Online Report 99-1: *Floodplain Mapping using HEC-RAS and ArcView GIS.* Center for Research in Water Resources. The University of Texas at Austin, Austin, Texas.

TxDOT, 1998. *Metadata: Digital County/Urban Map Files.* Internet Site: http://www.tnris.state.tx.us/DigitalData/TxDOT/metadata.htm

U.S. Army Corps of Engineers, 2000. *Geospatial Hydrologic Modeling Extension HEC-GeoHMS User's Manual.* U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.

U.S. Department of Agriculture, Soil Conservation Service, 1994. *Metadata: State Soil Geographic (STATSGO) data base for Texas*. U.S. Department of Agriculture, Soil Conservation Service, Fort Worth, Texas.

USGS, 1995. *Metadata: Hydrologic units maps of the Conterminous United States.* Internet Site: http://water.usgs.gov/GIS/metadata/usgswrd/huc250k.html

USGS, 1996. *Part 2: Specifications, Standards for Digital Orthophotos.* Internet Site: http://rmmcweb.cr.usgs.gov/public/nmpstds/acrodocs/doq/2DOQ1296.PDF

USGS, 1997. *Part 2: Hydrography, Standards for 1:24,000-ScaleDigital Line Graphs-3 Core.* Internet Site: http://rockyweb.cr.usgs.gov/nmpstds/acrodocs/core3/2CR30197.PDF

USGS, 1998. *Digital Orthophoto Program.* Internet Site: http://mapping.usgs.gov/www/ndop/

USGS, 1999. *National Elevation Dataset.* Internet Site: http://mac.usgs.gov/mac/isb/pubs/factsheets/fs14899.html

USGS, 2000. *Overview of the USGS Digital Raster Graphic (DRG) Program.* Internet Site: http://mcmcweb.er.usgs.gov/drg/drg_overview.html

USGS, 2000. *National Land Cover Dataset.* Internet Site: http://mac.usgs.gov/mac/isb/pubs/factsheets/fs10800.html

USGS, 2000. *The National Hydrography Dataset.* Internet Site: http://nhd.usgs.gov/chapter1/

Whelan, F., 1999. *Assessment of Hydrologic Properties and Land Use / Land Cover in Pacific Northwest Watersheds through Hydrologic Modeling Utilizing GIS.* Proceedings from the 19th ESRI International User Conference, San Diego, California. Oregon State University, Corvalis, Oregon.

# VITA

Sarah Anne Stone was born in New Haven, Connecticut on September 6, 1977, the daughter of Kathleen Anna Stone and Ronald Alan Stone. After graduating from Hopkins School in New Haven in the spring of 1995, she entered the College of Engineering at Cornell University in Ithaca, New York. She received a Bachelors of Science degree in Civil and Environmental Engineering from Cornell in May of 1999. In August 1999 she entered the Graduate School at the University of Texas at Austin.

Permanent address: 2 Maplewood Road
New Haven, Connecticut 06515

This thesis was typed by the author.